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RECREATIONAL BOAT SAFETY COLLISION RESEARCH

PHASE I

VOLUME I - PROBLEMS DEFINITION

Final Report

September 1975

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16. Abstract

The conditions surrounding recreational boating collisions were probed in an attempt to obtain the information required to document probable causes and possible collision reduction techniques.

This document summarizes the results of work done to date as well as required additional efforts, as follows:

Task I	Present collision investigation methodology.
	Present collision data handling systems.
	Present collision data coding methods.
Task II	Reports of collision investigations.
	Data analysis and discussions.
Task III	Effects of stressors on human performance.
	Effects of boat characteristics on human performance.
	Human engineering principles applied to the control station.
	Education as a method of collision reduction.

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FINAL REPORT

RECREATIONAL BOAT SAFETY COLLISION RESEARCH

PHASE I

VOLUME I - PROBLEMS DEFINITION

by

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September 1975

for

Work Performed Under Contract DOT-CG-40 672-A

Task Order 7

WYLE LABORATORIES

[redacted]

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INTRODUCTORY SUMMARY

According to the accident statistics published in CG-357, in 1973, the collisions of boats with other boats or objects accounted for over one-third of the total property damage and nearly 10 percent of the recreational boating fatalities. In addition, collisions accounted for 42% of the total number of accidents, and 54% of the total number of vessels.

During 1974, Wyle probed the conditions surrounding accident situations in order to direct the initial research necessary to obtain both statistical and investigative information required to document the probable causes and possible collision reduction techniques involving recreational boats. Although this initial effort is not intended to produce final details on causes, it is expected to have a high probability of payoff in determining the approach and magnitude of a continuing program which is intended to accomplish the above.

This report is intended to summarize the results to date of work done in Phase I of an ongoing research effort. Phase I was broken down into three interdependent tasks which are described below:

Task I was designed as an in-depth study into the Coast Guard's boating accident data handling system. Special emphasis was placed on the collision portion of that system. The accuracy of the statistics in terms of overall casualties were questioned. Major insurance companies' boating accident claims were analyzed in an effort to determine what may be a more accurate picture of the overall size of the boating accident problem area. An alarmingly large percentage of errors were noticed when a small sample of Boating Accident Reports (BAR's) were compared to the computer data for the same accidents. The errors were found and the problems discussed.

Because of certain problems inherent in the present cause coding methdology, a new form of coding is proposed. A group of accidents were coded using this method and results presented.

Work accomplished in Task I gave the contractor an intimate knowledge of the boating accident reporting system within Coast Guard Headquarters as well as a reasonable understanding of the causes of collisions as reported by individuals, police, and Coast Guard units through the BAR system.

Task II was designed as an in-depth study of the collisions themselves that would further define the causes of many re-occurring types of collisions. Sixty-nine collisions were investigated by telephone (screened) and six collisions were investigated in-depth.

The data was compared to the Coast Guard's statistical base. Finally, certain conclusions were drawn concerning areas for future research that might prove to be beneficial in reducing the rate of boating collisions.

Task III was designed as an in-depth study of the causes of collisions as defined by Task I and Task II. Since 60 to 90 percent of the collisions were coded as some sort of human failure, Task III looked into the problems surrounding human failure.

Human performance is degraded by stressors placed on the human. An experiment was run to determine if those stressors (i.e., heat, sun, fatigue, vibration, glare, etc.) actually affected the boat operator's performance and if it could be measured. The results are summarized in Task III, and the complete experiment documented in Appendix IIIA.

Other boat oriented stressors were looked at, measured, and compared to known human performance characteristics and tolerance limits. Included were such stressors as visibility, noise, shock and vibration, control forces, lateral acceleration, and control station design.

Finally, conclusions were drawn and recommendations were made.

Future research necessary to further define problem areas and define solutions that have a high probability of reducing the collision rate are proposed.

TASK I

TASK II

1.0 TASK I — PRESENT DATA SYSTEMS AND PROPOSED INVESTIGATION METHODOLOGY

1.1 INTRODUCTION

Task I is the first of a three part program designed to identify the underlying causes of boating collisions and propose a program to reduce the collision rate.

Task I has two major objectives: Collision Research Problem Identification and Coast Guard Accident Data Handling Systems Problem Identification. The data handling systems were studied from several viewpoints:

- Actual detailed investigation of BAR/MIO report handling and data processing procedures within Coast Guard Headquarters.
- Comparisons of narrative and BAR data with insurance underwriters data to establish confidence levels for the number of accidents reported.
- Interviews with field personnel who are involved with collision investigations and daily collision data handling.
- A collision investigation methodology for Task II was developed and is presented as part of Task I.

Task I, then, looks at the collision problem from the viewpoint of the data after the collision has been investigated and after all reports have reached Coast Guard Headquarters. In Task II, collisions are studied as they occur. Boat owners, drivers, passengers and witnesses are questioned in an attempt to determine causes. These causes are then compared to causes coded by the Coast Guard and studied as part of Task I. Task III will look at the causes as determined by Task I and II. An attempt will be made to identify the underlying problems and define an approach towards the reduction of the collision rate.

1.2 PRESENT DATA SYSTEMS

1.2.1 Published Statistics

The published statistics in CG-357, Boating Statistics 1973, show that the rate of recreational boating accident fatalities per 100,000 boats owned has remained fairly constant over the past several years, with the average rate approximately 20.9 fatalities per 100,000 boats. The rate for 1973 was 21.9 fatalities per 100,000 boats.

The number of reported accidents per 100,000 boats for 1973 was 84.1, and the number of all types of reported collisions (grounding, collision with another vessel, collision with a fixed object, collision with a floating object, and struck by boat or propeller) per 100,000 boats for 1973 was 57. It is suspected, however, that these accident rates are not realistic since many non-fatal accidents are probably not reported. If preliminary indications from other sources including insurance underwriters prove valid, then a more realistic reportable collision accident rate approaches 1,000 collisions per year per 100,000 boats or some twenty times the number actually reported. Section 1.2.3 discusses this problem in detail.

1.2.2 Bar Survey

A survey was made of the accident data handling systems at Coast Guard Headquarters. Boating accident report forms (BAR's) were followed from the time they entered Headquarters until such time as all data was extracted from them and they were filed away. The flow diagram, Figure 1-1 shows that the path of information from the BAR's to the computer and CG-357.

As a check on the data handling system, Wyle representatives correlated the data presented on BAR's with the data on the computer printouts for the same accidents. Nine MIO narrative reports of collisions and three BAR's of collisions were randomly picked from the 1972 files and compared to the data recorded on the computer printout of those collisions. In addition, one fire/explosion accident involving 14 boats was studied and compared to the computer printout. The reason for studying this accident was to determine how well the system handled an extreme situation, in this case a large number of boats involved in a single accident.

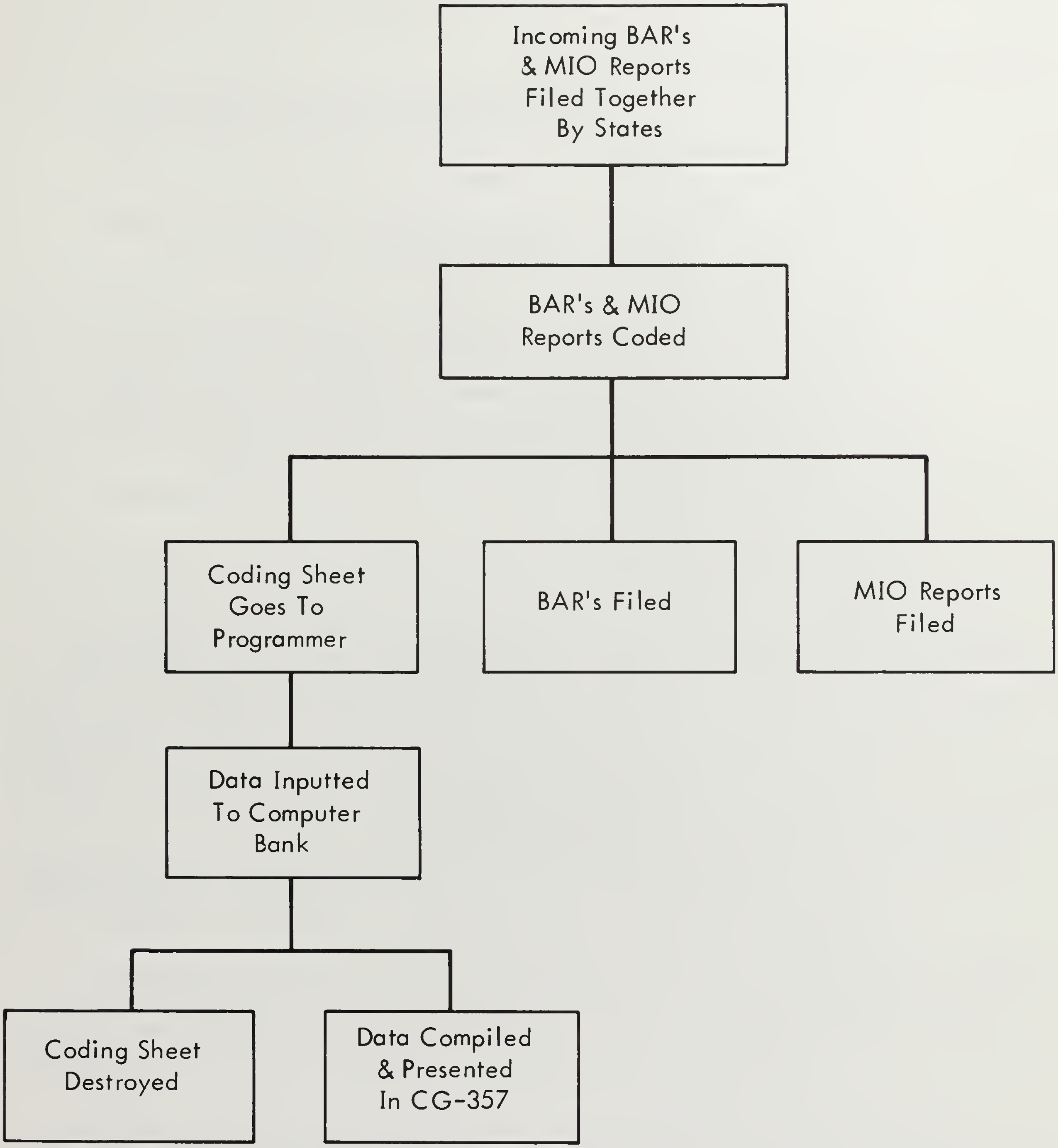


Figure I-1. Boating Accident Information Flow

The data of the 12 collisions are presented in tabular form, then discussed in detail. Twenty-four of the thirty-six columns presented on the computer printout are analyzed. The other 12 have been discarded since it is felt that they have no direct relationship to the accident situation.

Those parameters that have been discarded are:

1. Jurisdiction — This information has an insignificant bearing on the actual collision scenario.
2. District — Same as No. 1.
3. Case Number — Sorted in numerical order. Same as No. 1.
4. Date — Month, day, year.
5. Time — This is very important and, when sorted against several other parameters, could yield interesting information. However, the investigators were concentrating on the basic collision scenario; therefore, this column wasn't examined.
6. State — Same as No. 1.
7. County — Same as No. 1.
8. Water Type — The distinction between an inland river vs tidal river or inland lake vs tidal bay was deemed unimportant to the collision scenario, especially since water condition, visibility, wind, and weather are broken out into separate columns and were, of course, included in the relevant data base.
9. The column between the number of people drowned column and the number of people killed by other means column has no purpose. It is always coded "0".
10. Type of casualty — The printout was sorted to this parameter, i.e., "collisions". If an error had occurred in this column, the entire case would not have been printed out.
11. Number of Vessels Involved — Since the sort was collisions involving another vessel, the number should always read 2 except in the rate case of a multiple boat collision. Therefore, this column was not examined.
12. Federal Boating Act Code — Same as No. 1.

Since 11 of the 12 collisions picked involved 2 boats, 23 separate lines on the computer printout were studied and were treated as separate cases. Eight of the 23 cases picked from the files didn't show up on the computer printout, leaving 15 cases to compare against 24 columns for a total of 360 data points.

Statistics are as follows:

No. of data points that could have been coded	552
No. of data points that were coded	360
Percent of data points that were coded	65

Of the 360 data points that were coded:

No. of correct inputs	308
Percent of correct inputs	86
No. of errors	52
Percent of errors	14

Figure I-2 shows cases vs. information columns. Errors are shown with an X.

If the columns are ranked by number of errors in descending order, we find that the CAUSE column ranks highest with 8 errors or 53 percent error rate. It is reasonable to expect that the most errors would occur in the cause column since judgment is required to find the cause(s) as stated in the narrative or determine the cause(s) from the BAR, then determine the primary cause, find the nearest category in the cause code list, and enter that code number on the code sheet.

The investigators judged the cause coding errors as being errors when, in their minds, the cause as coded could not possibly have been construed as being either the primary or contributing cause of the collision.

Operator Formal Instruction and Boat Type are next with five errors or a 33% error rate.

Four of the five Operator Formal Instruction errors were coded as U (unavailable information) when the narrative and/or the BAR contained the information. The fifth error was a wrong number coded into the computer.

Case No.	90175 No. 1	90175 No. 2	90844 No. 1	90844 No. 2	90858	90897 No. 1	90897 No. 2	91164 No. 1	91164 No. 2	91469 No. 1	91469 No. 2	92018 No. 1	92018 No. 2	92222 No. 1	92222 No. 2	94307 No. 1	94307 No. 2	95397 No. 1	95397 No. 2	95830	95830	95860	95860	Total Errors	Percent of Errors
Percent of Errors	21	13	13	42	4	-	-	25	17	17	8	17	17	4	17			0	4					14.5	
Total Errors	5	3	3	10	1			6	4	4	2	4	4	1	4			0	1					52	14.5
Cause	X		X	X		NO INFO ON THIS COLLISION IN COMPUTER PRINTOUT	NO INFO ON THIS COLLISION IN COMPUTER PRINTOUT	X	X	X					X	NO INFO ON THIS COLLISION IN COMPUTER PRINTOUT	NO INFO ON THIS COLLISION IN COMPUTER PRINTOUT		X	NO INFO ON THIS COLLISION IN COMPUTER PRINTOUT	NO INFO ON THIS COLLISION IN COMPUTER PRINTOUT	NO INFO ON THIS COLLISION IN COMPUTER PRINTOUT	NO INFO ON THIS COLLISION IN COMPUTER PRINTOUT	8	53
Total Damage														X										1	7
No. Injured			X												X									2	13
Fatality Cause	X								X	X		X												4	27
Victim's Age										X														1	7
PFD's	X	X										X	X											4	27
No. Other Deaths									X															1	7
No. Drownings																								0	0
No. People Onboard				X				X																2	13
Operation											X				X									2	13
Wind																								0	0
Water Condition												X	X											2	13
Visibility																								0	0
Weather																								0	0
Rented Boat																								0	0
Horsepower	X			X																				2	13
Propulsion		X		X				X																3	20
Year Built			X	X									X											3	20
Length																								0	0
Hull Material				X																				1	7
Boat Type				X				X	X			X	X											5	33
Experience	X			X				X																3	20
Instruction				X				X		X	X				X									5	33
Operator Age		X		X	X																			3	20

Figure I-2. Data Error Analysis

X = Error

Under the Boat Type column, four of the five errors were from wrong numbers being coded while only one was coded U when the information was actually available.

The Lifesaving Devices Onboard column contained four errors, all coded "0" when, in fact, the MIO narratives were very specific on how many and what kind were available. It seemed as if the coders had not read the narratives, but based their coding decisions on the BARs only.

There was a special problem associated with the Total Damage column in that when the amount of damage is unknown, it was coded as 0000. The computer, therefore, thought that there wasn't any property damage associated with that accident. This error occurred in five of the 15 cases for a 33% error rate. In one case, the wrong number was coded.

In one case, only one of the BARs of a two boat collision had been received at the time of coding. Therefore, the details about the second boat were entered as U (unknown) or 0000.

Notice that the computer printout did not include information on 4 of the 12 cases. Because the sample is so small, one cannot predict the size of the overall problem. However, it can be said that the problem does exist. A sizeable number of accidents that have been reported and are on file do not get into the statistical data bank.

1.2.2.1 Further Investigation of BAR Coding System

Wyle personnel studied additional BARs, code sheets, and the computer printouts of the collisions to determine if BAR code sheets are the prime cause of differences between BAR data and the printouts of that data, rather than the prime cause being key punch errors.

Conclusion: Coding is the problem.

The BAR forms which are sometimes included in the narrative files, ask questions which are easily misunderstood by the person answering the questions. The following is intended only as a short discussion of some of the areas causing coding irregularities, and is not intended as a complete analysis.

The three boxes on a BAR headed "Boat Name," "Boat Make," and "Boat Model" are many times confused by the respondent. Because of the respondent's confusion, the coder is also confused and the manufacturer's code is many times incorrectly coded.

The "Type of Boat" categories are not definitive enough to match today's boat types.

The "Visibility" categories are not definitive enough as evidenced by the number of times that visibility at night is coded "Good," while the accident is described as happening because the operator never saw the other boat or object even though he was attentive.

The "Operation at Time of Accident" categories are confusing especially when more than one vessel is involved, and/or someone or something is in tow. The coder has to make a judgment as to one single code for several sequential or coincident operations.

The "Type of Accident" categories are very confusing as several may apply (no note is included on the BAR to mark more than one box, but the respondents do often times mark several) and are marked, but not in sequence. For example, if "Collision with a Fixed Object" and "Falls Overboard" are both marked, the coder may not know which came first when a comprehensive description of the accident is not included. Analysis of only the coded accident types, therefore, may lead to solving the wrong problems.

The categories marked by the respondent operator under "What, in your opinion, caused the accident" very seldom match the actual cause of the accident. More importantly, the respondent operator is asked to accept blame for an accident (if he is indeed at fault) without knowing the consequences. The effects of the question on the respondent operator are predictable. When the respondent is an officer of the law, the above bias is diminished.

"Property Damage (est.)" is not regularly noted. Most people do not know how to estimate costs.

Information about the deceased and injured is confusing since the form does not specify whether these victims are in the same boat, other boat, in the water or other. Multiple boat accident reports show the same victims listed on more than one report.

Accident descriptions, when furnished, are usually quite adequately descriptive and often times tell what really happened in spite of the other information on the form. Unfortunately, this information is not always used by the coder.

The coder is faced with coding answers for vessel casualty, contributing cause of fatality (which really means drownings only), cause, and secondary cause with one code for each when more than one might apply. Catch-all answers for causes can be easily rationalized by a coder but are not good foundations upon which to develop recommendations for methods which will lead to a reduction in boating accidents.

In order to identify additional problem areas, eleven more collision type cases were reviewed, all of which had taken place in 1974. Coincidentally, all eleven cases involved two boats. Only one BAR was on file for each of the eleven cases.

Columns 4-5-6 (Manufacturers Code) were incorrect in 3 of the 11 cases. In one other case, the coder's choice could have been either of two selections which indicated a problem. At this point, a quick review of the manufacturers code list showed that some manufacturers have the same name and several manufacturers have very similar names and some manufacturers have duplicate codes to indicate different plants. The BAR might list the "make of boat" correctly as Chris Craft, but the coder finds 12 manufacturer codes for Chris Craft and probably would have no way of determining which to use unless a HIN number is given. Likewise, if the BAR listed the "make of boat" as Atlantic, he probably would not have a way to accurately select the code from -

ABW	-	Atlantic Boat Works, Inc.
ATN	-	Atlantic Boats, Inc.
AFM	-	Atlantic Fibersteel Marine
AMA	-	Atlantic Marine
ASE	-	Atlantic Sci Eng Appl Co.

There are many other examples of similar duplications and similarities in the book.

Another problem in this same area is that the person completing the BAR report is confused by:

Boat Name — which could mean to him

- "My Treasure", or
- Hatteras, or
- Cruiser
- Etc.

Make of Boat — which could mean to him

- Glastron
- Wooden planked
- Runabout
- Etc.

Model of Boat — which could mean to him

- V-17
- 1972
- Outboard
- Etc.

In Case No. 22069, for instance, Boat Name was listed as MonArk and Make of Boat was listed as Aluminum. From this, the coder coded the manufacturer as ALU (Alumi Co.) instead of MAK for MonArk.

There were a few mistakes due to careless coding such as you might expect in this type of performance. In one case, the columns for horsepower were coded 035 for 35 hp, when the BAR listed the horsepower as 3.5.

Some correct information is written on the BARs in the wrong place, but a careful coder should pick up most of this information. For instance, in case No. 22072 the time was written in the a.m. space and the "a.m." was crossed out. The coder coded the time as 0100 even though the accident took place during waterskiing activity. Again in Case No. 22077 the BAR listed the type of propulsion as "2 Inboard Gasoline" but there were several references in the report to the fact that the boat was propelled by a water jet pump which according to the coding instructions should be coded "5-other (jet propulsion, sail, manual)."

In this case the code sheet needs changing to classify jets separately since there may be a trend towards a problem in collisions due to their speeds and handling characteristics.

The columns requiring decision making by the coder showed the most errors, such as shown for the manufacturer code. The "operation at time of accident" columns are prone to coder judgment error. The BAR might report such as "I was towing the skier when she fell down - I turned to the left to go get her when I hit the other boat." At this point, the coder can choose "03 - water skiing" or "02 - maneuvering." The coded sheets show a lack of consistency for this decision on the coder's part. A similar situation occurs if the boat was drifting while the occupants were fishing, etc.

The most consistent judgment error occurs in cause coding. The selections of the BARs for review were made from the "collision" file. All 11 BARs selected coincidentally involved two boats with one boat in each case underway and the other boat either underway or not underway. In all 11 cases, the faster moving boat was reported as striking the slower moving or stopped boat. In none of the 11 cases was the real cause so clear cut that one code number could cover the situation. Eight of the 11 cases were coded "05 - other person (includes improper parental supervision)." None of the 11 cases were coded 80 - other vessel.

It became obvious that "other person" was used by the coder as a catch-all for two boat collisions. A cause code list is taped on a filing cabinet in the coding room on which a star is placed next to 05 - other person (as a handy reference?).

In some cases, it was found that any one of the following codes could have been chosen by the coder — (Numbers refer to the Coast Guard Coding Instructions.)

01 - Speeding
03 - Improper lookout
05 - Other person (who was really in another vessel)
09 - Weather
13 - Excessive drinking
33 - Failure to yield right-of-way in a crossing situation

34 - Failure to alter course to starboard side in a collision situation

41 - Carelessness

42 - Disregard of weather or water conditions

44 - Rules of the road

50 - Poor judgement

51 - Recklessness

59 - Irresponsible

80 - Other vessel

85 - Bow in air obstructing view

89 - Attention taken up by other activities

It was evident that even if the accident reports were coded correctly originally or recoded correctly, the real causes of accidents would not become clear cut unless another type of coding system was developed and used.

The collision fault tree discussed in Section 1.2.5 was developed to more clearly indicate real causes which might be found in the existing accident report files.

1.2.3 Comparison Of CG357-1973 Data vs. Insurance Survey Data

Figure I-3 compares accident data from CG357, 1973, with an insurance survey covering the same year. The insurance survey includes boat owners insurance policy claims for property damage and medical payments, but does not include death benefit claims except for "other" persons.

Line 53, Column 6, shows that for all states, there are 0.84 accidents of all types reported by BAR's for each 1000 boats registered in the U.S.

Line 55 shows that for ten selected states (chosen because substantially all boats in these states are registered) the accident frequency rate of reported accidents per 1000 registered boats is 0.97.

Considering only the collision type accidents reported, lines 53, 54 and 55 show that the accident frequency rate for all states is 0.57 and for the selected ten states it is 0.70. All the frequency rates are less than one per 1000 registered boats.

Next, looking at the insurance survey data, line 53 in column 12 shows that for all states there were 15.06 claims (accidents of all types) for each 1000 boats surveyed as insured.

Line 55 in column 12 shows that for the ten selected states the frequency rate of accident claims per 1000 insured boats was 12.56.

Again, considering only the collision type accidents, for all states the frequency rate of accident claims per 1000 insured boats was 11.10 and for the ten selected states it was 8.78.

Comparing the number of collision type accident claims with the totals of all types of claims, we find that collisions accounted for 74 percent of the total for all states and 70 percent of the total for the selected ten states.

The percentages of collision type accidents relative to the total number of accidents in both the CG357 statistics and the insurance survey are high and quite consistant (68 to 74 percent).

Comparing the frequency rates from CG357 and the insurance survey, however, we find great differences.

Columns 14, 15, 16 and 17 show the ratios of frequency rates. In no individual case, except where data points are missing, is the frequency rate in CG357 greater than in the insurance survey. The comparisons of frequency rates of the totals show that the opposite is true. The frequency rate of collision type accidents for all states in the insurance survey is more than 19 times as great as the frequency rate reported in CG357. Likewise, for the ten selected states, the frequency rate is more than 12 times as great as that of CG357.

Most of these differences are felt to exist because of the different incentives to report the accidents. A boat owner will most certainly report an accident to his insurance carrier if he thinks that he is due some money (incentive by reward). He knows that he can benefit and he knows how to obtain the benefit.

There are less recognizable reward incentives for filing BAR's, and the boat owner's fear of a personal penalty may actually decrease the incentive for filing a BAR. Therefore, unless an enforcement officer encourages the boat owner to report an accident (incentive by fear) or unless the officer does it for him, the probability that the accident will go unreported is increased. Also, many boat owners are not aware that they are required to report an accident or what exactly constitutes a reportable accident. Thus, the vast differences in reported frequency rates could be explained.

State	Line	CG357 - 1973								Insurance Survey					Frequency Rate Comparisons Survey/CG357				Scope of Current State Boat Numbering System
Column		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
		Registered Boats	Registered Boats as a % of Total	Reported Fatalities	Reported Accidents	Reported Accidents as a % of Total	Reported Accidents Per 1000 Registered Boats	Reported Collision Type Accidents	Collision Type Accidents Per 1000 Registered Boats	Survey Number Insured as a % of Registered Boats	Survey Number Insured as a % of Total Insured	Survey Accidents as a % of Accident Claims	Survey Accidents Per 1000 Insured Boats	Survey Collision Type Accidents Per 1000 Insured Boats	All Accidents [Column 12/Column 6] 12/6		Collision Type Accidents [Column 13/Column 8] 13/8		
															R [1]	C [2]	R [1]	C [2]	
Alabama	1	147,940	2.3	41	111	2.1	0.75	58	0.39	7.5	2.8	2.2	11.30	9.04	15.07		23.18		All motorboats, sailboats, and rental boats
Alaska	2	17,473	0.3	35	71	1.3	4.06	20	1.14	1.9	0.1	0.1	8.90	8.90		2.19		7.81	All motorboats
Arizona	3	62,912	1.0	8	109	2.1	1.73	61	0.97	10.2	1.6	1.4	13.07	11.20	7.55		11.55		All watercraft
Arkansas	4	76,699	1.2	45	53	1.0	0.69	17	0.22	4.7	0.9	1.0	18.40	13.66		26.67		62.09	All motorboats of more than 10 hp
California	5	471,150	7.4	128	696	13.1	1.47	618	1.31	11.0	13.3	9.2	11.62	5.86	7.90		4.47		All motorboats and sailboats over 8 feet in length
Colorado	6	36,527	0.6	13	15	0.3	0.41	3	0.08	9.3	0.9	0.4	7.66	7.07	18.68		88.38		All motorboats and sailboats
Connecticut	7	64,506	1.0	18	67	1.3	1.04	68	1.05	7.7	1.3	1.5	13.52	11.30		13.00		10.76	All motorboats
Delaware	8	24,764	0.4	9	13	0.2	0.52	10	0.40	4.3	0.3	0.2	-	-		-		-	All motorboats
Dist. of Col.	9	4,130	0.1	5	5	0.1	1.21	-	-	13.0	0.1	0.2	1.86	1.86		1.54		-	All motorboats
Florida	10	273,069	4.3	124	374	7.0	1.37	282	1.03	17.3	12.1	11.8	14.13	11.11		10.31		10.79	All motorboats of more than 10 hp
Georgia	11	115,001	1.8	36	72	1.4	0.63	42	0.37	11.4	3.4	2.1	8.16	6.48		12.95		17.51	All motorboats of more than 10 hp
Hawaii	12	11,498	0.2	1	27	0.5	2.35	10	0.87	1.9	0.1	0.0	9.05	-	3.85		-		All motorboats and sailboats over 8 feet in length
Idaho	13	41,828	0.7	5	20	0.4	0.48	16	0.38	3.6	0.4	0.2	7.37	6.70		15.35		17.63	All motorboats
Illinois	14	209,354	3.3	69	127	2.4	0.61	98	0.47	10.3	5.5	2.3	17.52	4.82		28.72		10.26	All motorboats and sailboats over 12 feet in length
Indiana	15	104,695	1.6	19	30	0.6	0.29	11	0.11	6.7	1.8	1.7	18.32	0.72		63.17		6.55	All motorboats
Iowa	16	119,656	1.9	16	54	1.0	0.45	53	0.44	1.8	0.5	0.8	24.32	23.37		54.04		53.11	All motorboats
Kansas	17	70,209	1.1	14	28	0.5	0.40	12	0.17	4.5	0.8	0.8	12.42	8.60	31.05		50.59		All motorboats and sailboats
Kentucky	18	90,683	1.4	48	100	1.9	1.10	43	0.47	3.6	0.8	1.0	22.45	1.85		20.41		3.94	All motorboats
Louisiana	19	128,003	2.0	72	125	2.3	0.98	73	0.57	5.3	1.7	5.1	53.07	46.69		54.15		81.91	All motorboats of more than 10 hp
Maine	20	50,552	0.8	14	59	1.1	1.17	43	0.85	2.4	0.3	0.2	8.39	7.56		7.17		8.89	All motorboats of more than 10 hp
Maryland	21	80,046	1.3	44	196	3.7	2.45	144	1.80	12.1	2.5	2.5	8.13	7.00		3.32		3.89	All motorboats more than 7-1/2 hp; sailboats over 25 feet
Massachusetts	22	131,846	2.1	45	92	1.7	0.70	60	0.46	4.7	1.6	2.5	17.71	14.95		25.30		32.50	All motorboats
Michigan	23	593,061	9.4	94	392	7.4	0.66	268	0.45	3.2	4.8	4.1	14.35	13.92		21.74		30.93	All motorboats
Minnesota	24	417,101	6.6	35	107	2.0	0.26	82	0.20	2.1	2.2	1.5	11.22	9.14		43.15		45.70	All watercraft (with exceptions) [3]
Mississippi	25	44,328	0.7	26	45	0.9	1.02	29	0.65	5.9	0.7	0.9	23.01	16.49		22.56		25.30	All motorboats of more than 10 hp
Missouri	26	176,840	2.8	21	114	2.1	0.64	67	0.38	4.1	1.9	1.7	10.09	6.91		15.77		18.18	All motorboats of more than 7-1/2 hp
Montana	27	17,922	0.3	15	18	0.3	1.00	3	0.17	5.1	0.2	0.1	13.19	13.19		13.19		77.59	All motorboats of more than 8 hp
Nebraska	28	33,843	0.5	12	18	0.3	0.53	10	0.30	4.4	0.4	0.2	2.69	2.02		5.08		6.73	All motorboats
Nevada	29	20,618	0.3	5	87	1.6	4.22	32	1.55	16.1	0.8	1.1	15.64	8.42		3.71		5.43	All motorboats
New Hampshire	30	8,594	0.1	9	7	0.1	0.81	-	-	3.2	0.1	0.1	36.90	29.52		45.56		-	All motorboats
New Jersey	31	118,956	1.9	27	238	4.5	2.00	193	1.62	6.5	2.0	3.3	22.18	15.60		11.09		9.63	All motorboats
New Mexico	32	26,759	0.4	3	6	0.1	0.22	2	0.07	5.5	0.4	0.5	24.64	23.96	112.00		342.29		All motorboats and sailboats
New York	33	371,764	5.9	132	349	6.6	0.94	256	0.69	3.2	3.1	9.7	39.30	33.21		41.81		48.13	All motorboats
N. Carolina	34	104,548	1.7	51	132	2.5	1.26	97	0.93	5.4	1.4	0.9	9.94	7.81		7.89		8.40	All motorboats of more than 10 hp
N. Dakota	35	13,058	0.2	2	5	0.1	0.38	6	0.46	3.2	0.1	0.0	9.55	9.55		25.13		20.76	All motorboats of more than 10 hp
Ohio	36	231,379	3.7	73	145	2.7	0.63	90	0.39	5.7	3.4	4.4	18.57	16.75	29.48		42.95		All watercraft
Oklahoma	37	141,835	2.2	14	23	0.4	0.16	13	0.09	5.5	2.0	2.3	10.60	10.60	66.25		117.78		All watercraft
Oregon	38	103,182	1.6	17	83	1.6	0.80	47	0.46	8.4	2.2	1.4	11.70	9.38		14.63		20.39	All motorboats and sialboats 12 feet in length or greater
Pennsylvania	39	141,501	2.2	32	86	1.6	0.61	39	0.28	6.0	2.2	1.6	6.83	4.36		11.97		15.57	All motorboats
Rhode Island	40	14,920	0.2	6	36	0.7	2.41	37	2.48	9.0	0.3	0.5	14.85	11.14		6.16		4.49	All motorboats
S. Carolina	41	128,578	2.0	58	111	2.1	0.86	70	0.54	6.1	2.0	1.7	14.49	11.54		16.85		21.37	All motorboats
S. Dakota	42	19,421	0.3	7	12	0.2	0.62	9	0.46	1.7	0.1	0.0	6.10	-		9.84		-	All motorboats
Tennessee	43	174,729	2.8	47	72	1.4	0.41	38	0.22	4.4	2.0	1.5	12.61	10.14		30.76		46.09	All motorboats of 5 hp or more
Texas	44	432,863	6.8	95	231	4.3	0.53	143	0.33	6.5	7.2	7.9	18.30	15.33		34.53		46.45	All motorboats
Utah	45	31,219	0.5	6	65	1.2	2.08	34	1.09	5.6	0.4	0.2	9.67	8.53	4.65		7.83		All motorboats and sailboats
Vermont	46	22,339	0.4	13	8	0.1	0.36	-	-	1.8	0.1	0.1	22.28	19.80		61.89		-	All motorboats
Virginia	47	113,516	1.8	44	110	2.1	0.97	67	0.59	7.5	2.2	2.1	4.96	4.02		5.11		6.81	All motorboats
Washington	48	110,503	1.7	19	153	2.9	1.38	112	1.01	12.7	3.6	2.7	11.65	10.65		8.44		10.54	All motorboats
West Virginia	49	13,107	0.2	12	17	0.3	1.30	6	0.46	5.7	0.2	0.2	-	-		-		-	All motorboats of more than 5 hp
Wisconsin	50	354,155	5.6	52	166	3.1	0.47	141	0.40	1.2	1.1	1.6	23.66	21.76		50.34		54.40	All motorboats and sailboats over 12 feet in length
Wyoming	51	9,144	0.1	15	36	0.7	3.94	8	0.87	5.2	0.1	0.1	12.63	12.63		3.21		14.52	All motorboats of more than 5 hp
Others	52	26,498	0.3	3	6	0.1	0.23	1	0.04	-	-	-	-	-		-		-	All motorboats
TOTAL	53	6,339,678	100.0	1754	5322	100.0	0.84	3642	0.57	6.1	100.0	100.0	15.06	11.10	17.93		19.47		All motorboats
	54																		All motorboats
Ten Selected State Totals	55	1,259,199	-	-	1216	-	0.97	883	0.70	8.0	-	-	12.56	8.78	12.95		12.54		All motorboats

[1] R = "Real" because substantially all boats in these states are registered.
[2] C = "Conservative" because not all boats in these states are registered.
[3] Minnesota excludes (a) duckboats during duckhunting season, (b) sailboats, (c) canoes, (d) rice boats during harvest season, and (e) seaplanes.

Figure 1-3. Comparison — CG-357 Data vs Insurance Survey Data

1.2.4 Interviews

Wyle representatives interviewed several Coast Guard personnel experienced in accident investigations and one Harbor Patrol officer to determine how the reporting and investigation system works, the problems, what percentage of the collisions are reported, what is causing the collisions, and generally what can be done to prevent the collisions. It was felt that the information obtained would help to pinpoint problems and may even suggest solutions, but should be considered as opinion only.

Two of the people interviewed made some interesting inputs into the reporting and investigating system problem area, as well as on the percentage of reported collisions. First, a Fort Lauderdale Harbor Patrol officer said that during the month of June 1974, the Fort Lauderdale Harbor Patrol answered calls and investigated 15 boating collisions. As of the 15th of July, the Coast Guard knew of only one of these. The police reporting procedures are as follows:

> The Harbor Police send each accident report to the records division at the Fort Lauderdale Police Department. In addition, a monthly summary report is submitted to the City Police Department. Once yearly, the monthly reports are summarized for city-wide statistical purposes.

He claimed that these reports did not go to any state agency for distribution to the Coast Guard. Also, he didn't tell the people involved that they had to obtain, fill out and send in a Coast Guard form.

The MIO officer of a major boating city was also asked about the system. His response was that he and his group investigate only collisions resulting in a death. Prior to the investigation all applicable BARs are collected as are police reports and coroner's reports. The investigation consists of analyzing the information and filling out Form CG-4885 "Recreational Boating-Simplified Narrative." No telephone calls or field trips are made.

He felt that it was impossible to tell what percentage of the total number of collisions were reported to the Coast Guard. Each local Police Department in his area has their own data collection, retention, and reporting system; therefore, the records may or may not reach the proper department at the State level in a form that could be useful to the Coast Guard if passed on.

Presently, in order for the local Coast Guard district to be informed of the current boating accident situation, one or two concerned individuals within the local Coast Guard station must befriend the proper individuals within the local Police Department. Then, when a boating accident occurs and is reported to the Police, the individual at the Coast Guard office is contacted, and if possible, he accompanies the Police in their investigations. However, because this is based totally on individual effort, and under most circumstances involves a lot of off duty time, the practice is not commonplace. In addition, specific system benefits of combined Police/Coast Guard investigations are difficult to pinpoint, and therefore, many Coast Guard officers find it difficult to justify the time away from their official duties.

The main advantage would seem to be that the boat owners involved are told of their reporting responsibilities. Therefore, the probability that BARs would be submitted by all involved parties of a collision where the Coast Guard representative was a participant in the police investigation would be somewhat higher.

He felt that there should be a major change in the BAR system. The owner should not fill out and submit the BAR; the Official investigating the accident should do it. He is an uninvolved third party and, therefore, his report should be less biased.

He said it was ridiculous to conceive of car accident victims filling out their own accident report forms, then submitting them to the police. The accident profile would always be biased in favor of the person writing the report. However, we expect boating accident victims to assess their own accident, report it fairly, and identify the cause. In practice, he said, reports from owners of two boats involved in a collision usually vary so much that it is very difficult to extract the true story.

He added that since the local police are involved in most boat collisions of any consequence and are obliged to fill out their own reports, it would not seem inconceivable that a system could be devised where their report forms are standardized and one copy is mailed to the Coast Guard.

On the causes and remedies problem areas, one midwest MIO said that the predominant cause of collisions in his area was "lack of education." People with little or no boating knowledge buy a rig and head out on the lake. They do things that could be considered as "stupid" by experienced boaters and get into trouble. He added that forced education is the only answer, and he felt that this can only be accomplished through licensing.

A Second District officer said that "carelessness" was the most predominant cause of collisions in his area. Very few collisions had occurred because of equipment malfunction or other causes not directly attributable to the operator.

A Seventh District officer apologized for the fact that, although he has filled the billet of that person assigned to investigate pleasure boating collisions, he hasn't actually investigated any collisions to date. The only collision investigations being made are those made by the MIO office. However, those collisions that he was aware of in his district were all caused by operator error.

He felt that education could reduce the number of collisions, but not by much, since many of the collisions he was aware of happened because of what he called "gross negligence" such as traveling at 40 or 50 mph in congested areas. He felt that education wouldn't help the type of people who would do such "stupid" things.

The Fort Lauderdale Harbor Police Officer was noncommittal about specific causes but he said that the causes were generally not due to mechanical failures.

A Coast Guard officer in the Ninth District claimed that inattention, carelessness, speeding, poor judgement, and drinking were the most prominent causes of the collisions that his people have investigated. He didn't know of any specific machinery malfunction that caused a collision.

On ways to reduce collisions, he said education was the long term answer. In order to be effective, however, it must be done at the public school level. Programs similar to the automotive driving classes must be utilized to emphasize the inherent dangers.

He felt licensing would not be very effective since it would probably end up being fund raising in nature as opposed to educational in nature. However, it could very well be the most logical approach to raise the funds for education.

The same officer offered the following information on night operation of boats in his area. He felt that night driving was lethal. On one particular local lake the Police would not patrol in their boat at night for fear that they would be hit by one of the many speedboats traveling at full speed. Needless to say, many collisions occur there, especially at night.

In summary, the consensus of the interviewees seemed to indicate that there may be a problem with the overall collision reporting system. One person requested a total system change, wherein BARs are completed and sent to Headquarters by the local police officers who investigate the collision. Another person showed the interviewer that the Coast Guard was informed of only one collision out of 15. Some form of human error was mentioned as the predominant cause of collisions by all of the people interviewed. Most agreed that more and better education was necessary to solve the problem.

1.2.5 Fault Tree Analysis

As indicated in the BAR review, Section 1.2.2.1, the real causes of accidents will not become clear cut unless another type of coding system is developed and used.

The Fault Tree System was discussed as a possible coding approach. Various types of fault trees were looked at. A fault tree furnished by the Coast Guard representative (See Figure 1-4) was studied but was found somewhat difficult to use particularly with collisions involving two or more boats.

Another fault tree was subsequently developed and tested by coding the collision accidents that had been screened and/or investigated by Wyle during 1974. Further modifications were made to this fault tree and the version used for analysis is seen in Figure 1-5.

The narrative files were selected as the source for the collision research data because the information in the narratives is usually more detailed than on BARs, and the percentage of reported accidents is greater where a death is involved. An attempt to select specific types of case reports was made within time restraints, and photocopies were made of all pertinent information in those case files. The cases involving the listed vessel casualty types for:

- Grounding, coded 01,
- Collision with another vessel (including colliding with tow of another vessel), coded 07,
- Collision with a fixed object (above or below surface), coded 08,
- Struck a floating object (above or below surface), coded 09, and
- Struck by boat or propeller, coded 16

were sought.

A total of 119 case numbers were pulled from the 1973 narrative files and copied.

The 119 numbered cases from 1973 were reviewed and then coded by application of the fault tree codes. The results of the review and coding are as follows.

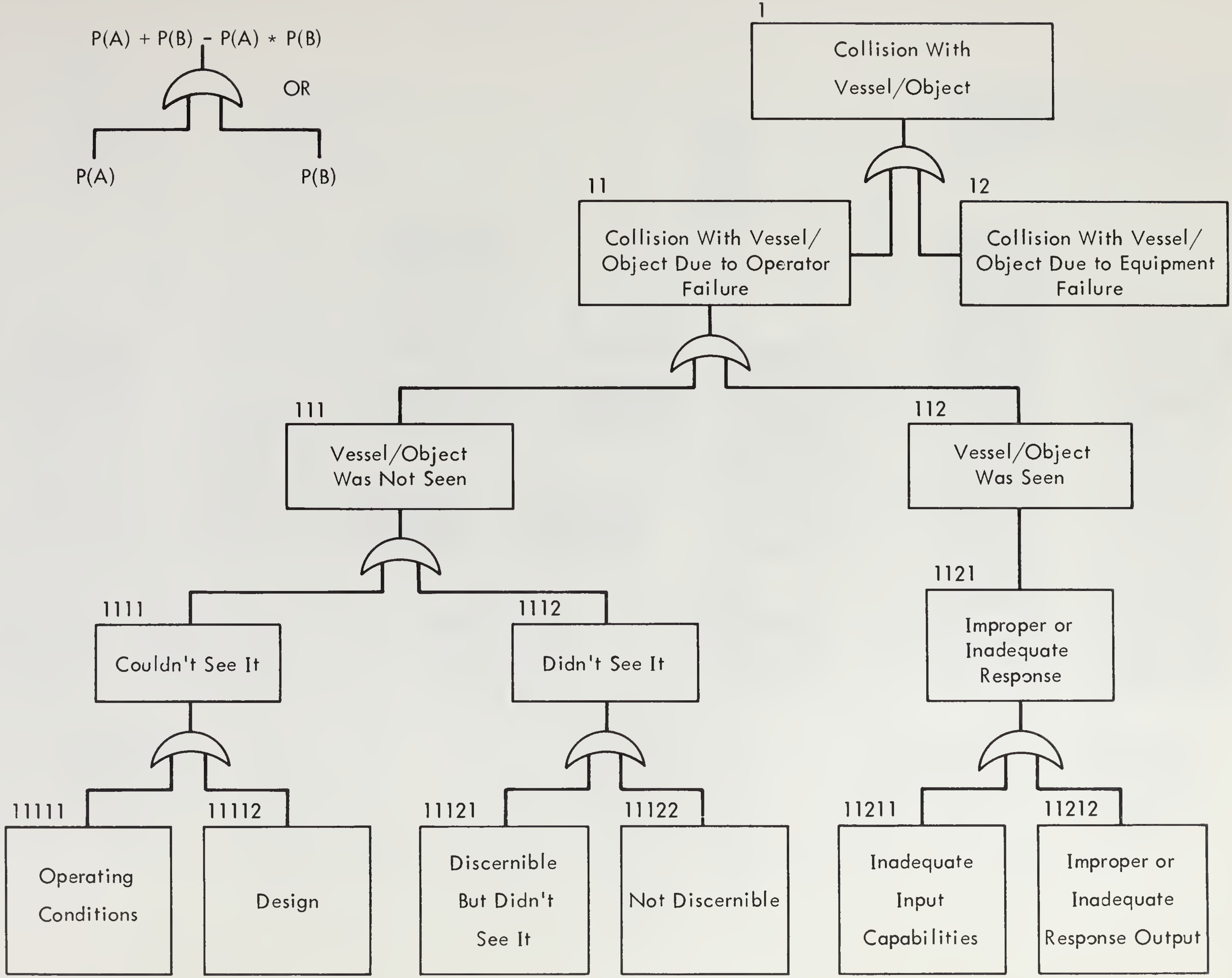
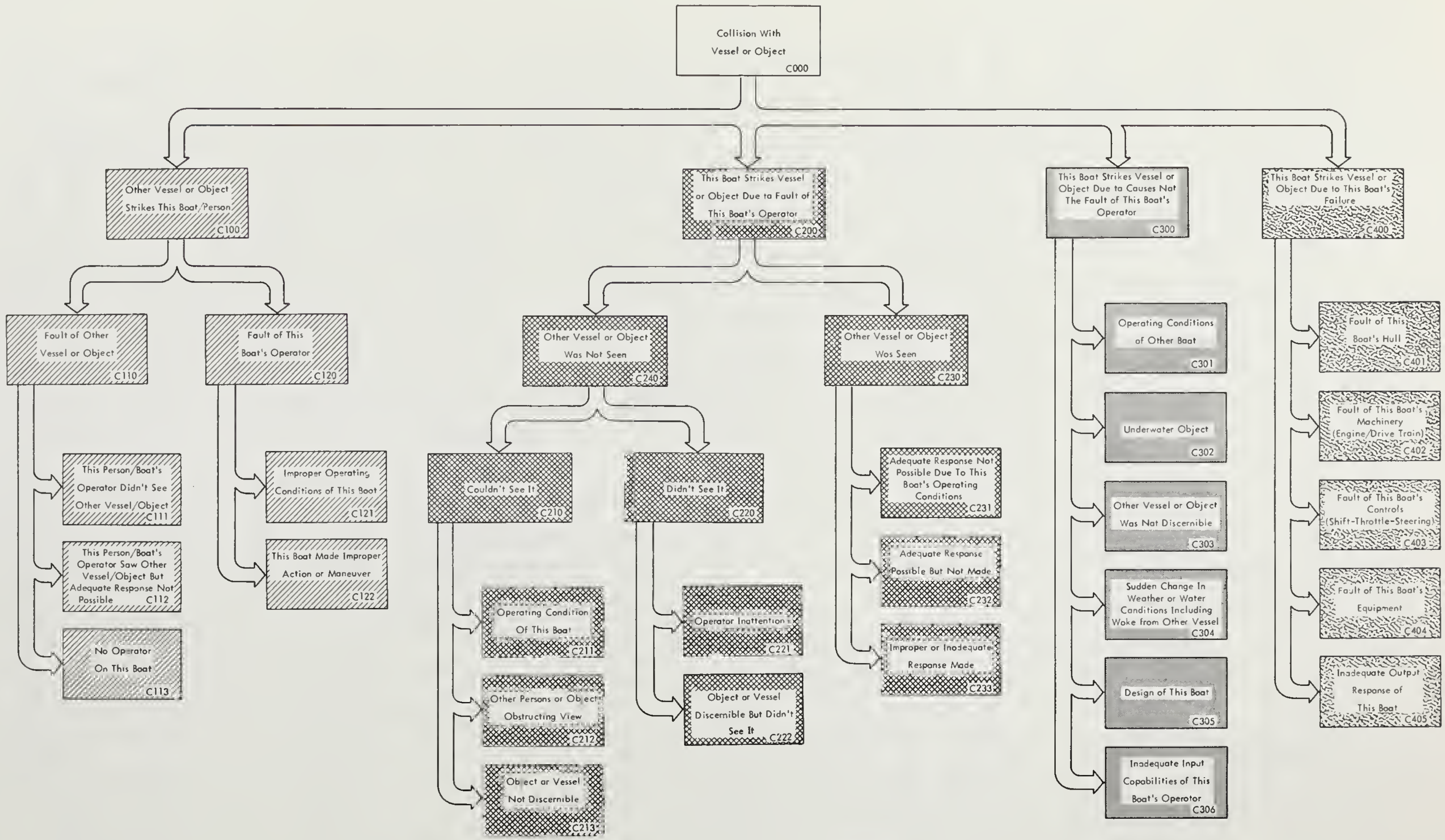
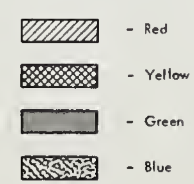


Figure 1-4. Collision Fault Tree





Code	Operational Causes
01	Proceeding too fast for conditions
02	Failure to yield
03	Improper lookout
04	Improper loading
05	Proper lights not displayed
06	Malicious actions
07	Out of control (operator at helm)
08	No operator at helm
09	Operator illness or impairment
10	Panic
11	Hazardous waters
12	Navigational errors
13	Alcohol or drugs
14	Out of gas

Code	Limited Visibility Causes
V1	Darkness
V2	Rain-snow-sleet-fog
V3	Sunglare
V4	Lack of contrast
V5	Glare from lights
V6	Improper lighting on fixed object
V7	Windshield dirty or obscured

Coding Directions:

Code as many causes as necessary to clearly describe the cause. Code all causes with an applicable Cxxx number followed by a two digit operational or limited visibility cause code as necessary.

For example: C211-04 means "Through the fault of this boat's operator, this boat struck a vessel or object which was not seen and could not be seen due to the operating condition of this boat which was improper loading."

Figure 1-5. Collision Fault Tree

Eight of the case numbers, or 6.7%, were duplicates of other case numbers, where other reports or photocopies of the same accident report were received from different sources at different times and each is given a separate case number. These duplications were removed prior to fault tree analysis.

Of the remaining 111 numbered cases, one case was found to actually have occurred in 1971 (a newspaper clipping from 1973 indicating the settlement of a resultant civil suit was numbered and in the file).

Of the remaining 110 numbered cases, 36 were not coded as any of the vessel casualty types 01, 07, 08, 09, or 16 although all but five of them should have been so coded and were considered worthy of coding by the fault tree.

For the purposes of this analysis, a collision involving more than one boat is considered as one accident.

The causes for the 105 cases were found to be grouped as follows:

- Sixteen cases, or 15.2%, did not involve any operator fault
- Eighty-five cases, or 81.0%, did involve at least some operator fault
- Four cases, or 3.8%, did not have sufficient information included to determine whether operator fault was involved.

When using the fault tree method for coding, in most cases it was found necessary to code more than one cause to adequately describe the accident situation. Rather than name one primary cause plus one secondary cause, the causes for each case were determined (no more than five causes were necessary for any one vessel) and weighted by contribution to the total cause so that they totaled 1.0 cause per case per vessel.

The 105 cases involved:

•	82	1 boat accidents x 1.0 weighted causes	=	82.0
•	22	2 boat accidents x 1.0 weighted causes	=	44.0
•	1	3 boat accidents x 1.0 weighted causes	=	3.0

so that the weighted total causes equaled 129.0

It must be remembered that the analysis is now biased by the addition of the second and third boat involvements so that the percent of operator failures is somewhat reduced from the 81% previously mentioned.

Figure 1-6 shows the breakdown of the total weighted causes C000 through C405 indicating that 83.1 of the 129 weighted causes (64.4%) were directly attributable to operator failure.

Considering the cause subcodes only for these 83.1 operator failure causes (see Figure 1-7), we find that 30.0% were due to improper lookout, 28.0% were due to proceeding too fast for conditions, 10.2% were due to operation in hazardous waters, and 11.5% were due to some form of limited visibility with darkness the major visibility factor at 9.9%.

Of the 105 cases, 10 single boat accidents involved only canoes or other boats without engines, not including sailboats. Four more cases involved sailboats whose aluminum masts came in contact with electrical power lines overhead. The remainder of the 91 cases involved one or more motorboats.

Considering only the 91 motorboat cases, the weighted causes (see Figure 1-8) show that 62.9% of the weighted causes were attributable to operator failure of which 32.1% of those causes were proceeding too fast for conditions, 31.0% were improper lookout, and 11.7% involved some form of limited visibility, of which darkness was the major visibility factor at 9.9%. The sub cause code for "hazardous waters" dropped substantially when the canoes and other non-powered boat cases were removed.

The high percentages of operator-failure caused accidents point out the need for an in-depth study of possible reasons for these operator failures. The five operational causes

- 01 Proceeding too fast for conditions,
- 02 Failure to yield,
- 03 Improper lookout,
- 04 Improper loading, and
- 05 Proper lights not displayed,

from the fault tree account for more than two thirds of the operator failures. All of these causes are readily controlable by the operator and therefore are affected by the several

stressors placed on the operator during operation. It is desirable then, to attempt to quantify the stressor effects on the operator in order to determine if an improvement can be made in the accident rate due to operator failure causes. Very few of the collisions reviewed occurred in the first few minutes of operation and most of those that did involved striking an underwater object.

Cause Code No.	Times Named As Cause	Weighted Total Causes		% of Each Weighted Total Cause	% of Weighted Causes by Failure Type			
					Unknown	Non-Operator Causes	Operator Failures	
C000	4	4.0	5.0	3.1	3.1			Unknown causes
C100	1	1.0		0.8	0.8			
C110	2	1.7	14.2	1.3		1.3		Non-operator causes — Hit by other boat/object
C111	4	2.7		2.1		2.1		
C112	7	7.8		6.0		6.0		
C113	3	2.0		1.6		1.6		
C120	3	1.7	83.1	1.3			1.3	Operator failures
C121	11	7.8		6.0			6.0	
C122	3	2.0		1.6			1.6	
C200	5	3.7		2.8			2.8	
C240	5	5.0		3.9			3.9	
C210	-	-		-				
C211	27	22.8		17.7			17.7	
C212	2	1.5		1.2			1.2	
C213	7	3.2		2.5			2.5	
C220	2	1.3		1.0			1.0	
C221	9	8.0		6.2			6.2	
C222	3	2.4		1.9			1.9	
C230	1	1.0		0.8			0.8	
C231	20	16.1		12.4			12.4	
C232	3	1.7		1.3			1.3	
C233	6	4.9		3.8			3.8	
C300	4	2.5	22.6	1.9		1.9		Other non-operator causes
C301	4	2.7		2.1		2.1		
C302	18	13.4		10.4		10.4		
C303	5	2.5		1.9		1.9		
C304	1	1.0		0.8		0.8		
C305	1	0.5		0.4		0.4		
C306	-	-		-				
C400	-	-	4.1	-				Boat and Equipment Failures
C401	-	-		-				
C402	3	1.9		1.5		1.5		
C403	3	2.2		1.7		1.7		
C404	-	-		-				
C405	-	-		-				
Total	157	129.0	129.0	100.0	3.9	31.7	64.4	

Figure 1-6. Breakdown of Total Weighted Causes, 105 Cases - All Boats

Cause Code No.	Operational Causes	105 Cases All Boats Operator Failures Only		91 Cases Motorboats Only Operator Failures Only	
		Weighted Total Causes	% Weighted Total Causes	Weighted Total Causes	% Weighted Total Causes
01	Proceeding too fast for conditions	23.3	28.0	23.3	32.1
02	Failure to yield	2.2	2.6	2.2	3.0
03	Improper lookout	24.9	30.0	22.5	31.0
04	Improper loading	1.8	2.2	1.8	2.5
05	Proper lights not displayed	0.9	1.1	0.9	1.2
06	Malicious actions	-	-	-	-
07	Out of control (operator at helm)	2.8	3.4	2.3	3.2
08	No operator at helm	0.3	0.4	0.3	0.4
09	Operator illness or impairment	-	-	-	-
10	Panic	-	-	-	-
11	Hazardous waters	8.5	10.2	3.0	4.1
12	Navigational errors	0.7	0.8	0.7	1.0
13	Alcohol or drugs	3.0	3.6	3.0	4.1
14	Out of gas	1.7	2.0	1.7	2.3
	Limited Visibility				
V1	Darkness	8.2	9.9	7.2	9.9
V2	Rain-snow-sleet-fog	0.8	1.0	0.8	1.1
V3	Sunglare	0.5	0.6	0.5	0.7
V4	Lack of contrast	-	-	-	-
V5	Glare from lights	-	-	-	-
V6	Improper lighting on fixed object	-	-	-	-
V7	Windshield dirty or obscured	-	-	-	-
	Undetermined	3.5	4.2	2.5	3.4
	Totals	83.1	100.0	72.7	100.0

Figure 1-7. Cause Subcodes for 83.1 Operator Failures, 105 Cases — Cause Subcodes for Operator Failures, 91 Cases

Cause Code No.	Times Named As Cause	Weighted Total Causes		% of Each Weighted Total Cause	% of Weighted Causes by Failure Type: Unknown	Non-Operator Causes	Operator Failures	
C000	3	3.0	4.0	2.6	2.6			Unknown
C100	1	1.0		0.9	0.9			
C110	2	1.7	14.2	1.5		1.5		Non-operator causes — hit by other boat/object
C111	4	2.7		2.3		2.3		
C112	7	7.8		6.8		6.8		
C113	3	2.0		1.7		1.7		
C120	3	1.7	72.7	1.5			1.5	Operator failures
C121	11	7.8		6.8			6.8	
C122	3	2.0		1.7			1.7	
C200	5	3.7		3.2			3.2	
C240	5	5.0		4.3			4.3	
C210	-	-		-			-	
C211	26	22.1		19.1			19.1	
C212	2	1.5		1.3			1.3	
C213	5	2.5		2.2			2.2	
C220	2	1.3		1.1			1.1	
C221	7	6.0		5.2			5.2	
C222	2	1.4		1.2			1.2	
C230	1	1.0		0.9			0.9	
C231	13	10.1		8.7			8.7	
C232	3	1.7		1.5			1.5	
C233	6	4.9		4.2			4.2	
C300	2	1.0	20.0	0.9		0.9		Other non-operator causes
C301	4	2.7		2.3		2.3		
C302	17	12.3		11.1		11.1		
C303	5	2.5		2.2		2.2		
C304	1	1.0		0.9		0.9		
C305	1	0.5		0.4		0.4		
C306	-	-				-		
C400	-	-	4.1			-		Boat and Equipment Failures
C401	-	-				-		
C402	3	1.9		1.6		1.6		
C403	3	2.2		1.9		1.9		
C404	-	-						
C405	-	-						
Total	150	115.0	115.0	110.0	3.5	33.6	62.9	

Figure 1-8. Total Weighted Causes, 91 Cases

1.2.5.1 Fault Tree Application

The collision coding fault tree used in the coding of the in-depth engineering accident investigations can also be used by the coders of BAR information.

It will be necessary, however, for the coders to thoroughly understand how to use the fault tree coding system correctly. In order that this understanding is accomplished, a brief training session may be required.

The training session should include at least explanations of the following:

1. The scope of applicability.
2. The purpose of fault tree coding.
3. How the data will be used.
4. The importance of accuracy and completeness.
5. The accountability methods used to check their coding.

It is recognized that there is a high probability that no accident will have only a single cause, but that the concert of coincidental events leading up to the accident will include multiple "causes." It is the purpose of this fault tree to identify in some detail what those causes are and to eliminate the "unknown" and "others" categories which have been coded frequently in the past. Multiple causes may be coded through the use of a weighting system discussed earlier.

The collision coding fault tree presented here has color added to aid the coder in his selections.

The suffix codes should be used where applicable for all causes. The fault tree was <u>not</u> expanded to include each of the suffix codes under each heading in order to simplify the figure to the point where it can be presented on a single sheet, recognizing that its simplicity will also aid the coder in making the correct choices.

1.3 DEVELOPMENT OF COLLISION INVESTIGATION PROGRAM

In order to develop a workable collision investigation program, an investigation plan had to be developed.

Wyle had to know about a collision within days after it happened in order to perform in-depth investigations. Witnesses had to be interviewed while the information was fresh in their minds and boat damage had to be studied before it was repaired.

Because it can take a minimum of several weeks to a maximum of several months for BARs to travel through the system and reach Headquarters, a short cut method of collision reporting had to be developed.

To aid the collision investigation program, as well as other accident programs, Coast Guard Headquarters set up a special telephone system from District and Local Units. They were to call a special number in the event of an accident in their areas and give pertinent information on the District, date, type of collision, casualties, and as much information on the names and addresses of the victims as possible. Headquarters, in turn, relayed the applicable collision information to Wyle.

Wyle personnel designed a special form used by the person receiving the information to insert the data as it was being dictated over the phone. The design goals of the form system was to reduce errors inherent in a verbal telephone data communication system.

The next step in the collision investigation program was to develop an organized telephone screening methodology. Since all reported collisions would not be investigated in-depth, decisions on collision causes would have to be made from the results of telephone conversations. In order for the interviewer to get an unbiased picture of the collision, an attempt would be made to call the reporting agency before calling any operators or owners involved. In that way, the interviewer would receive a relatively unbiased information base about the collision from the original investigating officer or from his report before talking with the victims.

An attempt would be made to contact both boat operators in the case of a two boat collision and as many witnesses as possible. The interviewer's problem, then, would become one of attempting to recreate the real collision scenario and attaching probable causes to it.

Forms were used in each step to assure uniformity and order. All forms used by Wyle interviewers are presented in Appendix I-A.

Next, a plan had to be developed to perform in-depth investigations. The interviewer had to be sure that he would be able to get enough information from both the boats and the people involved to recreate the collision in detail and determine the appropriate causes.

In order to maximize the probability that important information would not be overlooked, two more forms were created. The first was to be used to collect data from the boat. It would include detailed information on boat type, hull configuration, hull material, boat manufacturer information, including HIN, capacity information, basic dimensions, propulsion type and number, engine type and number, and information about the steering and shift/throttle control system.

A form was designed in such a way that the information was divided into four functional groups and presented in a way that, for the most part, the interviewer checked appropriate boxes arranged in columns. By proceeding in an orderly fashion through the form, the interviewer was assured of obtaining sufficient background information about the boat.

Boat damage information would be a combination of photographs and narrative.

Although the Coast Guard Inspection Officers that were interviewed indicated that they did not use any forms when interviewing collision victims and witnesses, Wyle personnel felt that forms would be necessary to help direct the interview in an orderly fashion. Several existing forms were looked at including a Swedish accident investigation form, one created by ORI for capsizing and swamping accidents and one created by Wyle for capsizing and swamping accidents. In each case, the questions were not oriented towards collisions and in the cases of the ORI and Wyle forms, were slanted towards capsizings and swampings.

Therefore a new interview report form was created. An attempt was made to organize the questions in such a way that the first portion of the interview included conversations about the boat, the passengers, and the weather. During that time the interviewer would attempt to establish a rapport with the victim or witness and make him or her feel at ease.

The actual questions concerning the collision were divided into three groups: pre-accident, accident, and post accident. If the interview report form format was followed, the interviewer could direct the respondant's narrative through the collision in an orderly fashion. The likelihood of the respondant skipping important points would, therefore, be minimized.

1.4 SUMMARY - TASK I

Task I was the first part of a three part program designed to identify the underlying causes of boating collisions and propose a program designed to reduce the collision rate. Task I looked at the collision problem from the viewpoint of the data after the collision had been investigated and after all reports had reached Coast Guard Headquarters.

An investigation of boating accident report data handling showed that as much as 15 percent of the information coded into the boating accident data bank may be in error, and, in fact, the majority of those errors were made during the coding process.

As may be expected, most errors were made on items requiring a decision of some sort on the part of the coder. The "cause" column had the highest error rate of those BAR's checked with 53 percent of the causes coded being in error.

The fault tree analysis system of coding accidents was proposed as a method of coding the causes of collisions that may lead to less coding errors and also more accurate cause data due to the fact that collisions having multiple causes may be coded accordingly.

Even though there were so many coding errors in the cause category, the errors seemed to be between forms of operator failure as opposed to being between operator failure and boat failure. So the percentage of operator failure to total collisions hasn't changed. The CG-357 statistics still say that people cause almost 90 percent of the collisions.

In an effort to determine how many collisions are actually reported to Coast Guard Headquarters, collision type accidents appearing as statistics in CG-357 were compared to the same type of accident claims of major insurance companies. It was found that the frequency rate of collision type accidents may be more than 19 times as great as the frequency rate reported in CG-357. For ten states in which all boats must be registered, the frequency rate is more than 12 times as great as that of CG-357.

Results of interviews with field personnel who are involved with collision investigations and daily collision data handling indicated that field personnel want the present BAR reporting

system changed and that many of the collisions reported to and investigated by city and state level people are never reported to the Coast Guard. Most interviewees agreed that more and better education was necessary to solve the collision problem.

Only a broad-based data analysis/cause identification effort has been completed in Phase I. The importance of human factors to the problem of recreational boating collisions has been confirmed. However, a complex problem remains. Questions of basic human capabilities are important. The effects of boat design on the environment are important. Boat design factors contributing directly to accidents are important. It is clear that the variables involved (such as type collision, type boat, type propulsion, mode of operation, maneuverability, time of day, weather conditions, type of water, water conditions, experience of operator, time on the water, type of activity, size of operator, strength of operator) and the cross-correlations possible are numerous. The Phase I data analysis effort has not been taken to the level of detail where the different values for each variable are correlated with all the remaining variables. However, as specific problem areas are identified based on accident investigations, text programs, and the analysis of current design practices (Tasks II and III), the appropriate analyses will be performed in subsequent phases of the project.

TASK II

2.0 TASK II — COLLISION INVESTIGATIONS

2.1 INTRODUCTION

In Task I, the collision problem was studied from the point where actual collision reports entered the data handling group at Coast Guard Headquarters to the point at which computerized accident data is published. The size of the collision problem was questioned and compared against insurance company statistics.

Task II actually backed up and looked at the collision problem first hand. It asked the question, "Is the data that gets to the Coast Guard valid?" It tended to fill the gaps in the problem identification task by picking up where it was impossible to go further with the Coast Guard data. It tried to find the causes of collisions by actually contacting those people that were involved in collisions as soon after the collision as possible. Those collisions with special "interest" were studied in-depth in an effort to learn as much as possible about the collision details and interactions of the people involved.

The Coast Guard data as presented in CG-357 says that almost 90 percent of collisions were caused by operator failure. Probable causes for these collisions were determined and grouped. The groups with the most number of collisions in them were looked at with special interest.

Ninety-six collisions were screened during 1974 and six were investigated in-depth. In this section, the results of the data obtained from the screenings and investigations are correlated and compared to the data found in CG-357. Deaths and injuries are compared to types of propulsion; number of collisions are related to boat length and collision type; and the time that the collisions occurred is discussed. Causes are separated into primary and contributing and are treated in detail. Collisions that occurred when it was dark are discussed in a separate subsection, as are the cause code lists and their usage. Finally, the collision investigation program is summarized and recommendations are made.

Actual reports of the in-depth investigations are presented under separate cover as Volume II.

2.2 BACKGROUND

Throughout the summer of 1974, Wyle screened and investigated boating collisions that were reported by Coast Guard Headquarters. Since collisions would have to be investigated

before damaged boats were repaired and witnesses got away or forgot the details, and since it normally takes a minimum of several weeks to a maximum of several months for boating accident information to reach the Coast Guard through "normal channels," Headquarters set up a collision reporting system designed to transmit basic collision data from a local Coast Guard unit to Headquarters and onto Wyle as quickly as possible. The system seemed to function since most weekend collision data was received by Wyle early in the following week.

2.2.1 Collision Screening

Figure 2-1 is typical of the data supplied to Wyle on an actual collision. Note that the section entitled "Screening by Wyle" has not been completed. This section has been replaced by the form shown in Figure 2-2 "Contact Report," which allows for greater detail and multiple contacts associated with the same collisions.

The screening process included calling the owners and operators of all boats involved, witnesses, and the Coast Guard unit or Harbor Patrol that handled the case.

An attempt was made to get the respondent to give a narrative of the entire collision scenario. The interviewer's task was to keep the conversation going in the right direction, ask questions to help fill in the gaps and record the conversation on the interview forms detailed in Task I.

In most cases the owners and operators cooperated with the interviewer; however, in several cases where deaths occurred, the owner of the boat that did the hitting refused to talk. This was understandable and conclusions were drawn around the other respondent's statements.

2.2.2 Post Screening Summaries

After weighing all of the statements in each collision, the interviewer wrote a short collision summary and applied possible causes to that collision.

Those collisions which were to be considered for further investigation were identified by a process of elimination, i.e.,

- Collisions whose causes were immediately identifiable and had no other data interest to the Coast Guard.
- Collisions where one or more parties were uncooperative or couldn't be reached were eliminated.
- Collisions where, after screening, it was obvious that there would be no impact on standards, regulations, or education were eliminated.

The remaining collisions generally involved suspected hardware defects, repetitive accidents impacting standards and regulations, and those which could contribute to a broader understanding of the nature of collisions. These remaining collisions were further screened to determine which would actually be investigated. Criteria included number of witnesses and witness availability, the boat(s) availability, and the distance between boats and witnesses. Also considered was the type and size of boats involved and the type of activity that the boat was involved in at the time of the collision. Because only a limited number of collisions could be investigated, an attempt was made to find as broad a spectrum of boating activity, etc., as possible.

2.2.3 In-Depth Investigations

Six collisions were investigated in detail. All six are presented and discussed in Volume II of this report. A brief summary of each follows:

2.2.3.1 Collision 1

At 1:30 a.m. on the morning of 23 June 1974, a 17 ft speedboat overran a 27 ft pontoon type houseboat. The speedboat hit the houseboat to starboard of the centerline of the transom, slid up onto the aft deck and exited the starboard side of the houseboat approximately 10 ft forward of the transom. The houseboat owner suffered the only injury, the houseboat capsized, and the speedboat had only minor damage.

2.2.3.2 Collision 2

At 2:30 p.m. on the afternoon of 13 July 1974, two open motorboats collided. A 14 ft john boat was coming off plane, while a 14 ft open boat swerved into his path. The john boat had minor damage. The topsides of the open boat fractured and the boat swamped, spilling its occupants. No one was injured.

2.2.3.3 Collision 3

Just after dark on the evening of 14 July 1974, two speedboats, each travelling at approximately 30 mph, collided head on. Upon impact one boat climbed the bow and flew completely over the other boat. The driver of Boat A never saw Boat B. The driver of Boat B saw and tracked Boat A until impact, always thinking it was going to turn. One person in each boat was injured. The boats suffered minor damage.

2.2.3.4 Collision 4

Just before noon on 9 July 1974, a 24 ft twin engine cabin cruiser attempted to pass a 60 ft motor yacht. The 24 ft boat suddenly swerved in front of the 60 ft yacht and was hit amidship. One person in the 24 ft boat was injured. Both boats were damaged.

2.2.3.5 Collision 5

A 14 ft open power boat hit a 16 ft sailboat broadside. After initial impact, the powerboat flew over the sailboat, carrying away the mast and rigging and injuring four of the five people on the sailbcat. The steering system on the powerboat reportedly failed prior to the collision.

2.2.3.6 Collision 6

An 18 ft outboard was dead-in-the-water in an open bay with motor troubles. It was 0900 on a clear morning with a one to two foot chop on the bay. A 23 ft deep-vee inboard/outboard cuddy cabin runabout ran into and capsized the 18 ft outboard boat. One person drowned. Damage was relatively minor.

ACCIDENT NO. 82

INFORMATION REPORTED TO WYLE BY G-BBC

TYPE ACCIDENT: Collision — DATE OF ACCIDENT: 7-11-74 DATE RECEIVED REPORT: 7-24-74

USCG UNIT MAKING REPORT: CG Group, Long Island Sound, 203/469-6471

DESCRIPTION OF ACCIDENT: — with barge cable NO. INJURIES/FATALITIES: ________

DESCRIPTION OF BOAT: (Include Registeration or HIN) 33' (1967) two inboards - 300 hp each

BOAT OWNER: (Include name, address, phone, etc.) Walter Tchick, 274 Pine Creek Avenue,

Fairfield, CT 203/259-6063

TENTATIVE BOAT AVAILABILITY: East End Yacht Club - Bridgeport, CT

INDIVIDUAL RESPONSIBLE FOR BOAT: ________

COMMENTS: ________

SCREENING BY WYLE

ACCIDENT ACCEPTED FOR INVESTIGATION? ________

INDIVIDUAL(S) CONTACTED: (with date) ________

WHO REPORTED ACCIDENT? ________

TO WHOM WAS ACCIDENT REPORTED? ________

IS OWNER/OPERATOR/WITNESS AVAILABLE? ________ IS BOAT AVAILABLE WITH OWNER'S PERMISSION TO USE? ________

IS WATER AVAILABLE? ________ DISTANCE FROM BOAT? ________ TRANSPORTATION? ________

MARINA FACILITIES AVAILABLE FOR LIFTING HEAVY BOAT? ________ DESCRIPTION OF BOAT: ________

MATERIAL: ________ HULL FORM: ________ AGE: ________

BOAT REGISTERATION NO. OR HIN: ________

COMMENTS: ________

Figure 2-1. USCG Notification of an Actual Collision

CONTACT REPORT

Contact Report Of: COLLISION # 82

Date Of Contact: 15 AUG 74 - 1500 Telephone ☒ Visit ☐

Follow Up Date: ______________

Agency Or Company	
Personnel	MRS TKHICK
Location	
Phone	203/259-6063
Code	
Purpose	GET MNE INFO
Discussion	- WENT UNDER BRIDGE - CONSTRUCTION ON OTHER SIDE - CABLES STRUNG ACROSS WATER HOLDING BARGE IN PLACE - SWERVED TO MISS ONE - HIT ANOTHER - ALMOST DARK - OTHER BOATS HAD HIT CABLES - NOW THEY ARE MARKED -
Action	- NONE!
Copies To:	

549 Rev.

Figure 2-2. Contact Report

2.3 Data

Sixty-nine collisions were reported to Wyle from Coast Guard Headquarters during the period of 29 May 1974 through 9 September 1974. Fourteen of the 69 reported collisions were not screened for various reasons such as:

- Boat owners had unlisted telephone numbers or no telephone at all
- Wyle had wrong names or addresses
- Boat owners were unwilling to discuss the collisions
- Boat owners were out of town or otherwise unable to be interviewed
- Etc.

Therefore, information from 55 collisions was used for the data base. Details of each collision were put in tabular form for the purpose of comparison. See Figure 2-3. Details of the tabulated headings and some justification of the hows and whys follow.

2.3.1 Wyle Number

Wyle has similar contracts to study capsizings/swampings, and john boat accidents. All accidents are reported to Wyle as described above, are given a number in numerical order as they are received. Collisions are pulled from the file of all accidents but retain their original number. Therefore the "Wyle numbers" in the first column are not consecutive.

2.3.2 Accident Month/Day

No comment needed.

2.3.3 Time

Some times were approximated. Witnesses may not have known the exact time but knew that it was "about an hour after dark," or "sometime after midnight," etc.

2.3.4 Primary Cause

After studying each case, a primary cause, or that action which, after it had occurred, made the collision imminent, was recorded.

2.3.5 Contributing Cause

All causes or actions which could have contributed to the operator or the boat getting to the point at which the collision was imminent. Also included in this column are the primary causes. In general, when operator error is involved, the more known about the collision, the more contributing causes are listed.

2.3.6 Total Damage

In most cases the damage figure had to be guessed. The screenings and investigations took place so soon after the collisions that insurance companies had not had a chance to assess the damages.

2.3.7 Deaths and Injuries

No comment needed.

2.3.8 Boat Types

I/O	=	Inboard/Outboard
I	=	Inboard
O	=	Outboard
S	=	Sailboat.

2.3.9 Boat Sizes

Boat sizes are given in feet.

2.3.10 Collision Types

Two boats	=	Two or more boats collide
Fixed object	=	One boat hits a submerged, surface, or overhead fixed object
Non Fixed Object	=	One boat hits a submerged, surface, or overhead non fixed object.

2.3.11 The Numbers

Because the sample was small and because only collisions that Coast Guard Headquarters selected and reported to Wyle were used in the sample, it was felt that it did not have statistical significance; and, therefore, was not treated as such. However, the data has been compared to the data in CG-357 and is summarized below.

	Summer 1974		CG-357 - 1973	
	Total	Per Collision	Total	Per Collision
Deaths	7	.12	153	.06
Injuries	36	.65	724	.26
Property Damage ($)	126,000	1484	3,215,400	883
No. of Boats Involved	85	1.55	2772	1.24
No. of Collisions	55	NA	2233	NA
Avg. Boat Length	24.6 ft		21.7 ft	

The data has been broken down into more or less functional groups and compared to data from CG-357 as follows.

2.3.12 Deaths and Injuries Vs. Types of Propulsion

In order to simplify the comparisons, deaths and injuries were combined into one group called casualties. Casualty data were compared to the type of propulsion to determine which, if any, type of boat produced a higher rate of casualties.

To do this, the number of boats involved in collisions where a death or injury occurred were determined from both the 1974 summer study and CG-357.

Next, the overall number of boats involved in all reported collisions were determined from both sources. A comparison of the data should reveal which types of boats produce more casualties per collision. All numbers were converted to percent of total for comparison purposes (see Figures 2-4 and 2-5).

Both sets of data indicate that there were more inboard boats involved in collisions than any other type. But although there were less collisions involving outboard boats, the number of casualties stemming from outboard collisions was more than double that of the next highest casualty column.

Wyle No.	Accident Mo.	Doy	Time	Primory Couse	Contributing Couse	Totol Domoge	Totol Deaths	Totol Injured	Boot Types		Boot Sizes		Collision Type: Two Boats	Fixed Object	Non Fixed Object
011	06	11	1500	89	89	00500	0	0	I/O	-	26	-		×	
014	06	12	U	71	71	00800	0	0	I	-	27	-			×
015	06	29	1900	24	24	01000	0	1	I	-	20	-		×	
017	06	16	0100	47	47	15000	0	0	I	-	41	-		×	
023	06	24	1200	46	46	00300	0	0	I/O	-	20	-		×	
					01										
024	07	02	1200	71	71	00800	0	0	I	-	28	-			×
027	06	22	0200	42	01	01000	0	1	O	I/O	27	17	×		
					13										
					35										
					42										
031	06	22	U	01	01	02000	3	1	O	O	20	16	×		
					42										
034	06	25	0000	35	13	00050	0	0	O	I	16	50	×		
					35										
					38										
					41										
035	06	26	2000	89	42	01000	0	2	I	I	26	38	×		
					89										
046	07	04	1600	01	01	01000	0	1	O	U	16	U	×		
					41										
048	07	04	1400	34	34	00300	0	2	O	I/O	14	17	×		
					37										
049	07	05	U	71	71	04000	0	0	O	-	20	-			×
053	07	09	1100	43	01	03500	0	0	I/O	I	24	60	×		
					43										
054	07	11	2300	35	01	01000	0	0	I	O	23	18	×		
056	06	26	U	09	09	00400	0	0	I	I	45	42	×		
058	07	13	1430	89	01	00500	0	0	O	O	17	13	×		
					37										
					41										
					89										
065	07	13	1500	29	29	00500	0	0	O	I	17	27	×		
					52										
					56										
067	07	14	2100	34	01	01500	0	2	I/O	O	19	18	×		
					08										
					34										
068	07	14	1130	07	07	U	0	0	I	I	16	19	×		
					52										
072	07	20	2300	13	13	00500	0	2	I/O		16			×	
076	07	21	1600	71	06	01500	0	0	I	-	23	-			×
					71										
077	07	21	1600	71	28	00500	0	0	O	-	14	-			×
					71										
080	07	22	1800	71	71	01500	0	0	I	-	28	-		×	
081	07	23	0600	41	41	01000	0	0	O	I	25	50	×		
082	07	11	2000	01	01	02000	0	0	I	-	33	-		×	
					42										
083	07	14	0030	01	01	01000	2	0	O	-	16	-		×	
					41										
085	07	28	1330	88	88	04000	0	0	S	S	42	38	×		
					89										
086	07	29	0400	35	35	00200	0	0	O	O	14	14	×		
					41										
					89										
087	07	30	1400	46	46	00300	0	0	I	O	24	16	×		
088	07	30	1300	89	24	00500	0	3	O	S	16	14	×		
					52										
					89										
089	08	02	U	13	13	00400	0	0	I	U	26	U	×		
090	08	01	U	71	71	00300	0	0	I	-	30	-			×
095	08	05	1400	89	41	00100	0	0	O	I	14	50	×		
					89										

Figure 2-3. Collision Data

Wyle No.	Accident		Time	Primary Cause	Contributing Cause	Total Damage	Total Deaths	Total Injured	Boat Types		Boat Sizes		Collision Type		
	Mo.	Day											Two Boats	Fixed Object	Non Fixed Object
098	08	09	2200	34	34	02300	0	U	I/O	I/O	26	18	x		
					37										
					89										
102	09	10	2200	01	01	06000	1	5	O	-	18	-		x	
					42										
104	08	10	1200	41	41	00050	0	0	S	I	14	50	x		
					50										
					52										
					89										
106	08	12	0400	01	01	06000	0	3	I/O	-	21	-		x	
					42										
108	08	12	1700	89	89	05000	0	1	O	-	16	-		x	
112	08	14	2200	01	01	06000	0	4	I	O	22	18	x		
114	08	16	1600	20	20	06000	0	1	O	-	20	-		x	
					50										
117	08	15	1800	41	41	01600	0	1	O	O	14	16	x		
					52										
121	08	18	U	71	71	00700	0	0	I	-	19	-			x
124	08	17	1700	89	89	00300	0	0	S	I/O	14	20	x		
126	08	18	1920	89	89	00400	0	0	I/O	I/O	20	17	x		
139	08	31	0900	89	08	01000	1	1	O	I/O	18	23	x		
					85										
					89										
140	08	31	1300	34	34	00500	0	1	O	I	16	18	x		
					37										
142	08	31	1500	43	52	00100	0	1	I	O	24	16	x		
					43										
144	09	01	0900	89	01	01000	0	0	I	I/O	25	18	x		
					88										
					89										
146	09	01	U	51	41	05000	0	2	I/O	U	16	U	x		
					51										
					43										
148	09	01	2330	89	41	04000	0	0	O	I	16	50	x		
					52										
					89										
155	09	12	2200	47	01	06000	0	0	I	-	25	-		x	
					42										
					47										
156	09	07	1100	47	47	12000	0	0	I	-	28	-		x	
158	09	07	2230	89	89	12000	0	1	I	I	37	36	x		
159	09	10	2200	47	47	01200	0	0	I	-	30	-		x	
					50										

Figure 2-3. Concluded

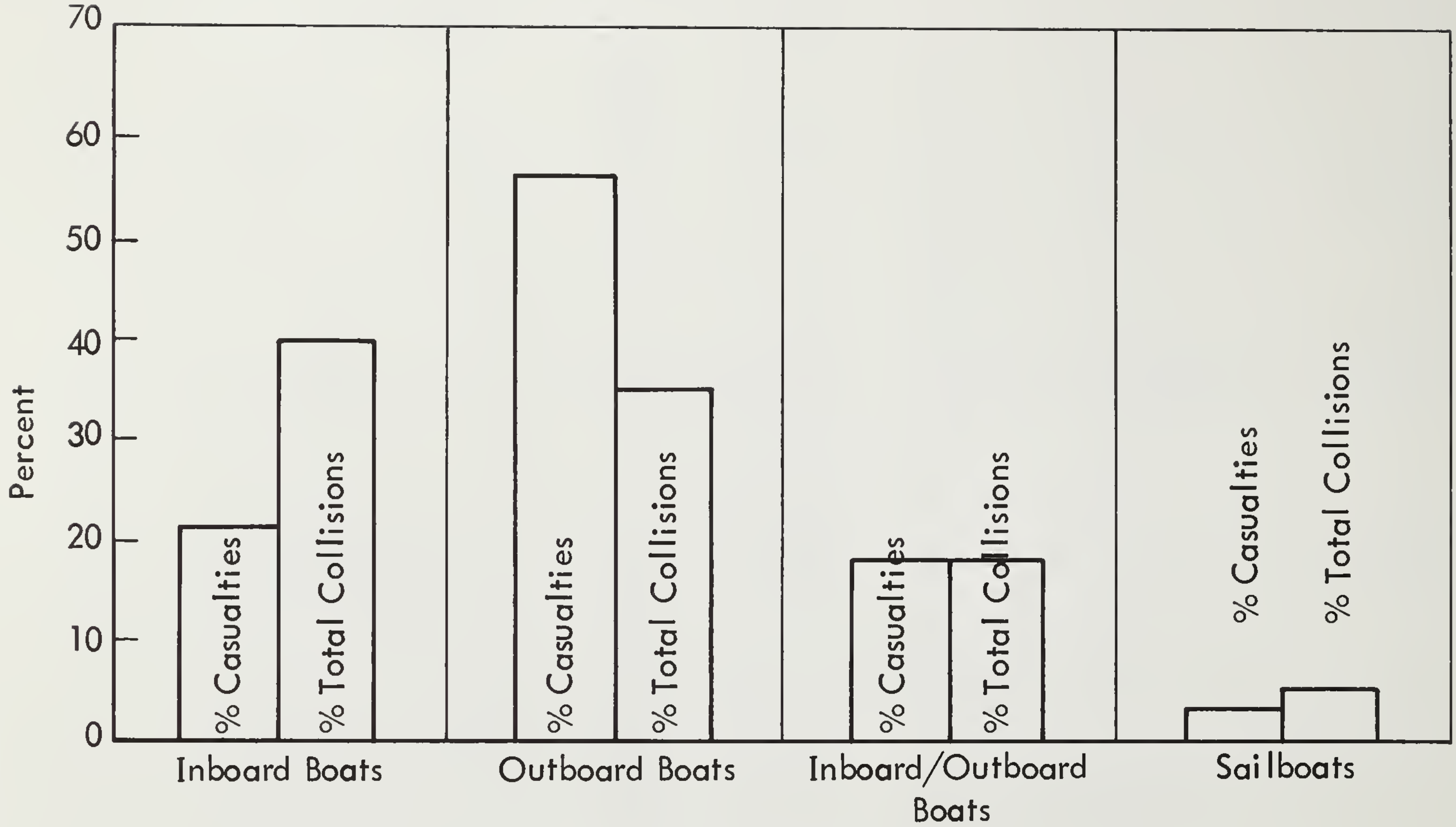


Figure 2-4. Results of 1974 Summer Study

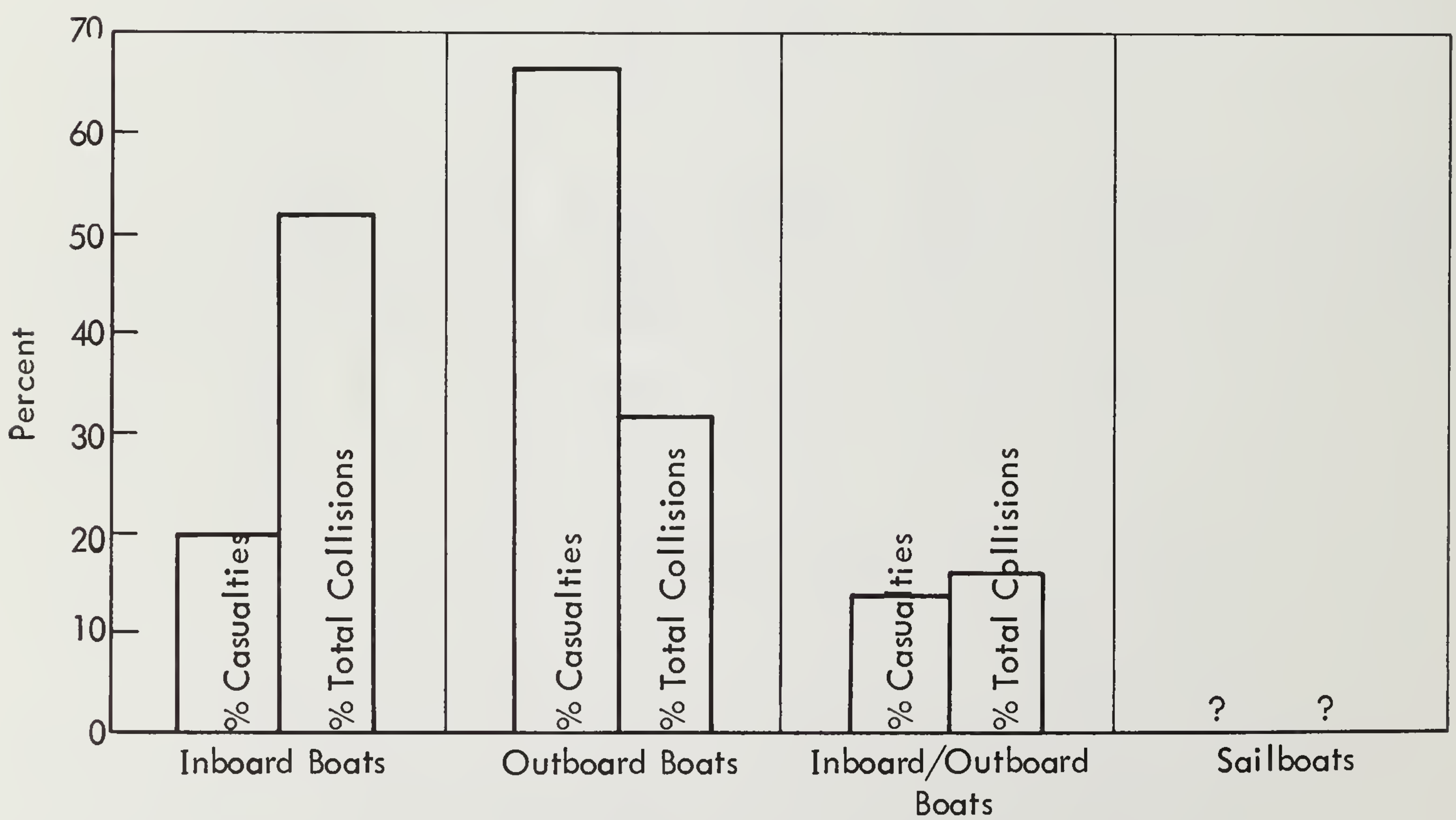


Figure 2-5. Data From CG-357, 1973

2.3.13 Boat Lengths

Boat lengths vs. number of occurrences were tabulated and compared against similar data from CG-357, 1973.

The data are presented in CG-357 in terms of classes, i.e., A, 1, 2, 3. Therefore, the summer study data were converted from individual lengths to classes for the purpose of comparison. See Figure 2-6.

Note that the summer study shows less percentage of boats in Class A and more in Classes 1 and 3. The differences can be better understood by comparing average boat lengths between the summer study and CG-357 collision data:

	Average Boat Length
Summer Study	24.6
CG-357	21.7

The three foot difference in average boat lengths may be the result of the reporting system. For the most part, only Coast Guard units reported the collisions. Since they are generally located along a coast line, it would be reasonable to expect a population of boats in the vicinity that would be larger than the average population of boats throughout the country.

2.3.14 Types of Collisions

Types of collisions were treated in the same way. That is, the types of collisions from the summer study were compared against the 1973 data from CG-357. Results are shown in Figure 2-7.

Note that we are dealing with percentage of vessels, not collisions. Since the "fixed object" and "non fixed object" collisions involve only one vessel, a similar polot of collisions would show the "two boat" columns as being half as tall as they presently are. Both sets of data agree that more than twice as many two boat collisions occur than the next highest category.

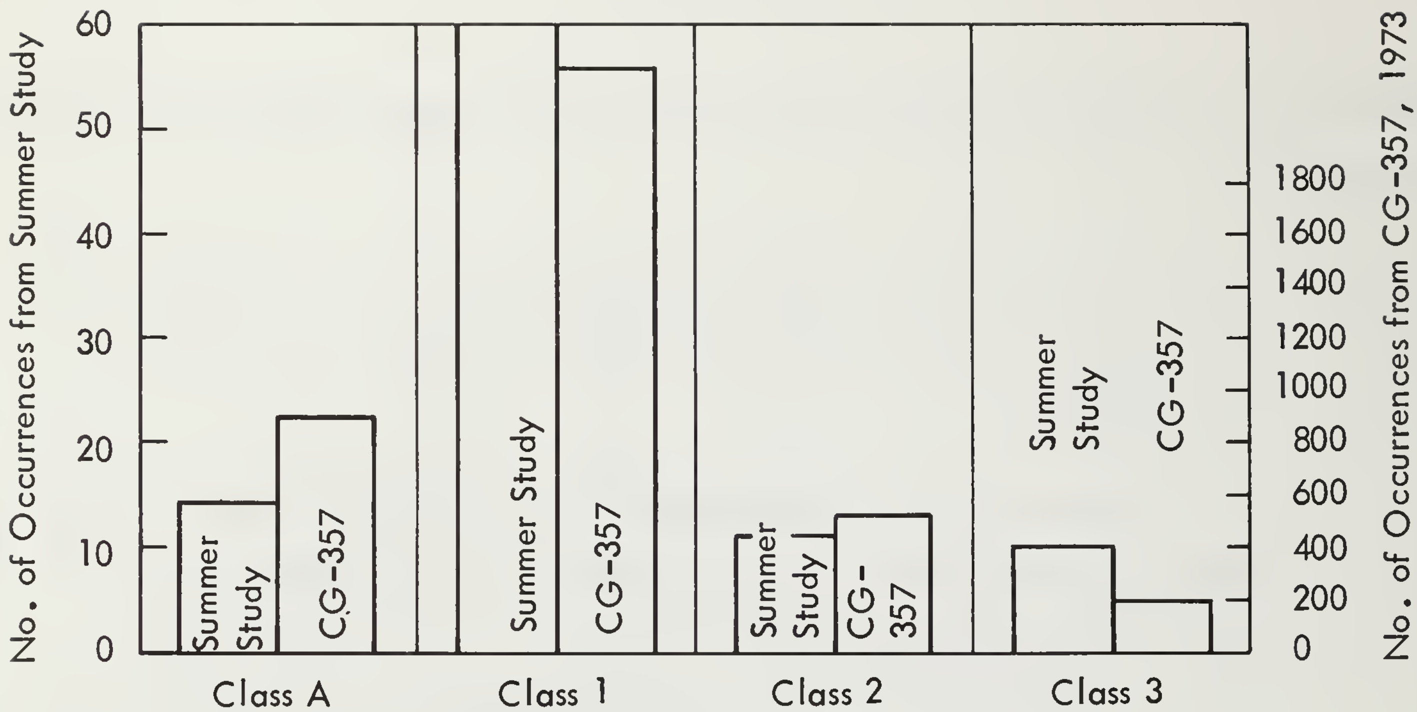


Figure 2-6. Boat Length vs. Number of Collisions

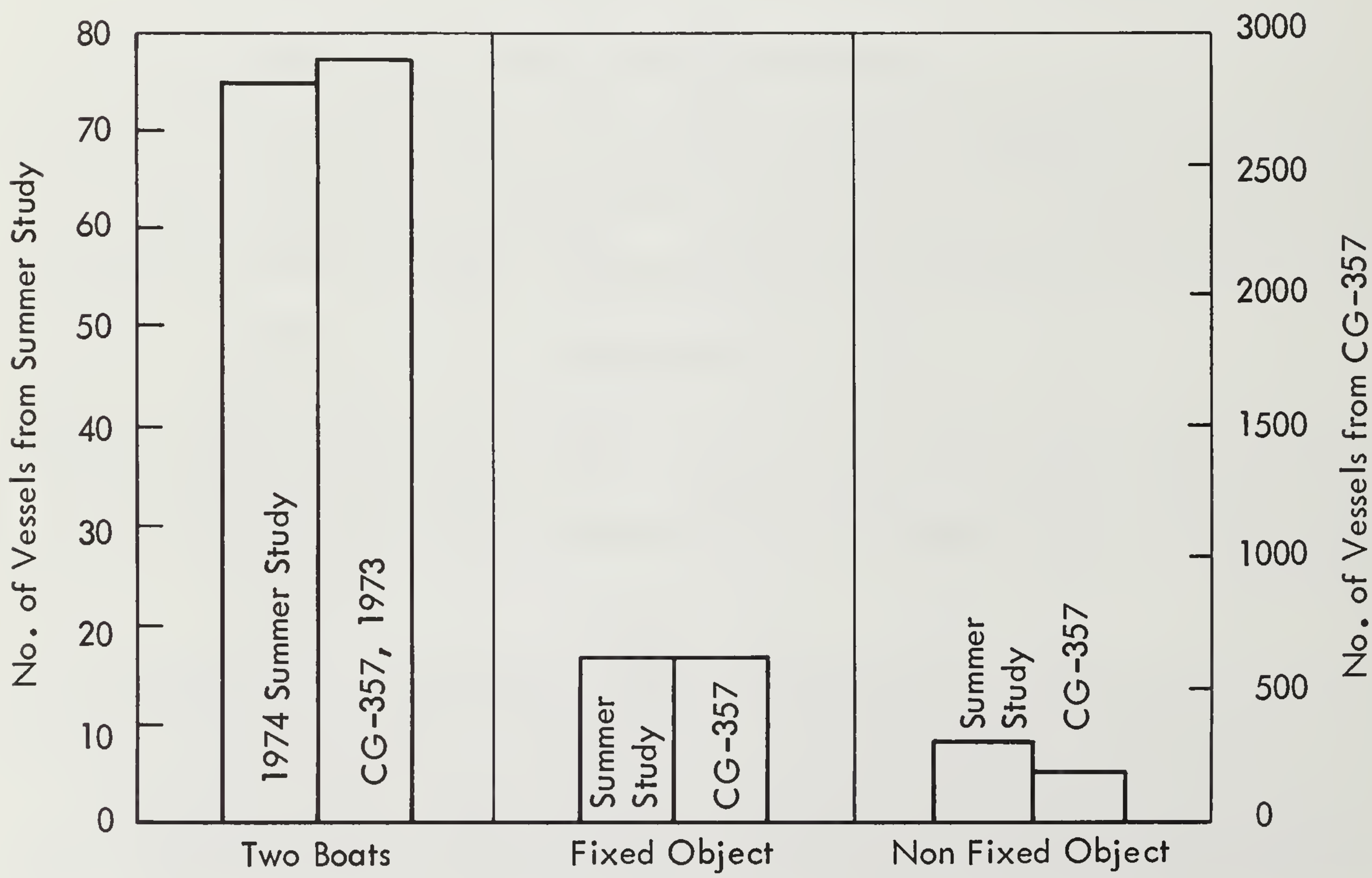


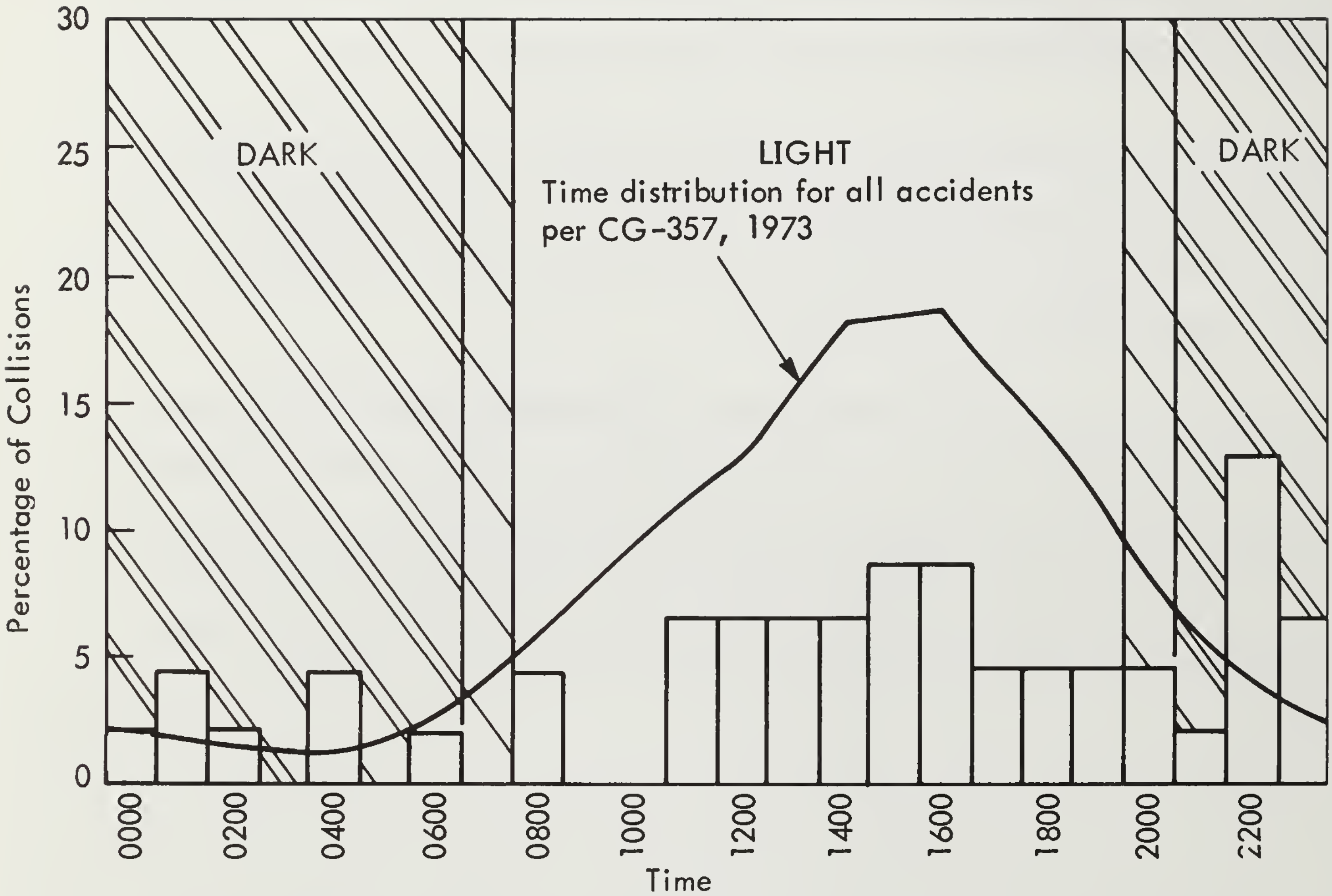
Figure 2-7. Collision Type vs. Occurrence

2.3.15 Time of Collisions

Each collision was plotted against time and compared to the CG-357 data from all accidents. CG-357 does not plot time data on collisions alone. Therefore, the value of comparing the two is questionable unless one makes the assumption that the time distribution of all boating accidents is similar to the time distribution of collisions alone. Wyle has not made that assumption but presents the data for information purposes only.

In Figure 2-8, an attempt was made to distinguish between collisions happening during daylight hours and those happening at night. Because of the obvious peak just after dark, and the fairly high level of collision activity throughout the night, night-related collisions have been treated separately. See Section 2.5.

Note that the 1974 summer study data do not show a pronounced peak in mid afternoon as do the CG-357 data. In fact, the collisions tend to be evenly distributed throughout the day from 1000 to 2400. The pronounced peak at 2200 may be due to the screening system used. In attempting to get times from the witnesses and operators, an answer of "it happened about an hour or two after dark" was acceptable and was coded as 2100 or 2200.



(Bars Indicate Percentage of Collisions At That Time in 1974 Summer Study)

Figure 2-8

2.4 Causes

2.4.1 Primary Causes

One or more primary causes and appropriate contributing causes were assigned to the six collisions that were investigated in depth. In addition, probable causes were assigned to all collisions that were screened by telephone. For comparison purposes, a single primary cause was chosen from each of the 55 collisions and recorded in order of number of occurrences.

For coding and comparison purposes, causes from the present Cause Code List were used because they are numbered and can be compared to existing Coast Guard data.

It is interesting to note that only 18 of the available 89 causes were used and of those the top four causes accounted for over half of the collisions.

Inattention was coded as the primary cause for 22% of the collisions. This tends to be a catchall phrase and should probably replaced by more specific causes in order to be able to better determine how and why the collision occurred. Inattention was distributed fairly evenly among inboards, outboards, and I/Os; therefore, it doesn't seem as if the operator of any given type of boat is any more or less attentive than the operator of any other type of boat.

Speeding accounted for 13% of the collisions. Outboard boats were involved in 64% of the collisions where speeding was coded as the primary cause. This is predictable since outboard boats generally are capable of going faster than either inboard boats or I/O boats.

Hit submerged object also accounted for 13% of the primary causes of the collisions. Here, the predominant boat type was inboard. This too is predictable since modern inboard boats tend to have their shafts, struts, propellers, and rudders exposed under the hull, and therefore, more susceptable to damage than either outboards or I/Os which have the kick up capability.

Cause	Code No.												
Inattention	89	I/O -	I I	O O	O S	O I	O -	S I/O	I/O I/O	O I/O	I I/O	O I	I I
Speeding	01	O O	O U	I O	O -	O -	I/O -	I O					
Hit Submerged Object	71	I -	I -	O -	I -	O -	I -	I -					
Failure to Turn to Stbd to Avoid Collision	34	O I/O	I/O O	I/O I/O	O I								
Careless	41	O I	S I	O O	I -								
Navigation Error	47	I -	I -	I -	I -								
Rules of Road (lights)	35	O I	I O	O O									
Alcohol	13	I/O -	I U										
Lack of Caution in Congested Area	43	I I/O	I O										
Lack of Operator Experience	46	I/O -	I O										
Control Defect	07	I I											
Weather Conditions	09	I I											
Steering Defect	20	O -											
Steering Failure	24	I -											
Control System Failure	29	O I											
Disregard of Weather/ Water Conditions	42	O I/O											
Recklessness	51	I/O U											
View Obstructed By Moveable Object	88	S S											

First designation in block represents boat # 1, second designation represents boat # 2, if applicable.

Each block represents one collision.

I = Inboard
O = Outboard
I/O = Inboard/Outboard
S = Sailboat
U = Unknown
\- = Not Applicable

Figure 2-9. Primary Collision Causes — 1974 Summer Study. Type of Boat(s) Indicated in Blocks

Failure to turn to starboard to avoid a collision accounted for 7% of the primary causes of the collisions. Of those, outboards and I/Os were involved in all but one instance. This tends to indicate that outboard and I/O drivers are less aware of or don't abide by the rules of the road as compared to inboard boat drivers. Again this is predictable since the inboard or larger boat operators are probably more experienced and tend to know the rules of the road better than the outboard or I/O drivers.

Careless also accounted for 7% of the primary causes of the collisions. There doesn't seem to be any one predominant boat type that is involved in a collision whose primary cause is judged as careless.

Navigation error — It is interesting to note that all collisions whose primary cause was coded as navigation error (7% of total) involved inboard boats. Apparently operators of inboard boats tend to wander farther from home and, hence, get into unknown waters where navigational errors eventually lead to a collision with either the bottom or an unseen submerged object. Three of the four navigational error collisions occurred at night. All four involved navigational aids in that the aids were there, and if seen and interpreted correctly would have directed the boat operator to the appropriate safe course. Hence the collision would have been avoided.

Rules of the road (lights) accounted for 5% of primary causes of all collisions. Lights and nighttime collisions in general are discussed in Section 2.5 .

The remaining 25% of the primary causes were distributed among eleven categories, and will not be discussed. However, there is one factor that is probably significant that did not surface in the data comparisons. That is that all three sailboat collisions occurred because one of the sails blocked the helmsman's view of the oncoming boat. In the cases where the other boat was seen at the last instant, there wasn't time to make the necessary corrective actions to avoid the collision.

2.4.2 Contributing Causes

Contributing causes were defined as all causes or actions which could have contributed to the operator or the boat getting to the point at which the collision was imminent. Therefore, contributing causes include both primary and secondary causes.

There were 108 contributing causes coded for the 55 collisions in 27 different categories. Thirty percent of the available 89 code categories were utilized. Since the code categories are general and are used for all types of pleasure boating accidents, the 30% usage rate is probably reasonable to expect. The contributing causes, listed in descending order of number of occurrences are shown in Figure 2-10.

In comparing the contributing cause data to the primary cause data we find that:

- The two most frequent causes are still <u>inattention</u> and <u>speeding</u>, but speeding is now equal to inattention indicating that speeding was a major contributing factor in many of the collisions whose primary cause was something other than speeding.

- <u>Carelessness and disregard for weather/water conditions</u> advanced upward in the list indicating that these too were major contributing factors in many of the collisions whose primary cause was something other than carelessness.

- <u>Improper action/reaction in emergency situation</u> didn't appear on the primary Cause Code List but ranks as sixth on the contributing cause list, again indicating that it was a major contributing factor in many of the collisions whose primary cause was something else.

- On the other hand <u>failure to turn to starboard to avoid a collision</u> was only coded as a primary cause, never as secondary and, therefore, slipped down the list.

The remainder of the contributing causes are not discussed because they either didn't move significantly or the number of occurrences were low.

	Cause Codes From Coast Guard List	Wyle Collision Case Number Indicated														
Speeding	01	23	27	31	46	53	54	58	67	82	83	102	106	112	144	155
Inattention	89	11	58	85	86	88	95	98	104	108	124	126	139	144	148	158
Carelessness	41	34	46	58	81	83	86	95	104	117	146	148				
Hit Submerged Object	71	14	24	49	76	77	80	90	121							
Disregard for Weather/ Water Conditions	42	27	31	35	82	102	106	155								
Improper Action/Reaction in Emergency Situation	52	65	68	88	104	117	142	148								
Rules of Road (Lights)	35	27	34	35	54	86										
Alcohol	13	27	34	72	89											
Failure to Turn to Stbd to Avoid Collision	34	48	67	98	140											
Rules of Road (Maneuvering)	37	48	58	98	140											
Navigation Error	47	17	155	156	159											
Lack of Caution in Congested Area	43	53	142	146												
Poor Judgement	50	104	114	159												
Illegal Lighting	08	67	139													
Steering Failure	24	15	88													
Lack of Operator Experience	46	23	87													
View Obstructed by Moveable Object	88	85	144													
Hull Defect	06	76														
Control Defect	07	68														
Weather Condition	09	56														
Steering Defect	20	114														
Hull Failure	28	77														
Control System Failure	29	65														
Out of Gas (Carelessness)	38	34														
Recklessness	51	146														
Bow in Air Obstructing View	85	139														
Starting Vessel with Clutch Engaged	56	65														

Figure 2-10. Contributing Causes of 55 Collisions - Collision No. Indicated

When the list is viewed as a whole, it is interesting to note that the top half of the list, or 76% of the total number of causes, were operator error oriented with the exception of a majority of the cases in "hit a submerged object" category. The remaining 24% of the total number of contributing causes were almost equally divided between operator errors and equipment failures.

It is difficult to compare the causal results of the 1974 summer study with the causes as listed in CG-357 because in the summer study, each collision was treated as a unit, whereas in CG-357 each vessel involved in the collision is treated as a unit. Therefore, in CG-357, one finds 27% of the causes listed as "fault of other person" as meaning, for the most part, fault of the other vessel.

An attempt was made to correlate the two sets of data into a bar chart as shown in Figure 2-11.

As anticipated, correlation between categories was not good. When the percent of collisions was compared to percent of total vessels involved in collisions, the categories within CG-357 didn't fit the summer study data in three of the 11 causes.

However, both sets of data showed that the predominant number of collisions were caused by operator errors including, no proper lookout and excessive speed. The summer study showed that 91% of the primary causes involved operator error, while CG-357 shows 89.5% to be caused by operator error. The assumption was made that "fault of other person" was an operator error in CG-357.

Only 82% of the collisions were caused by operator error when the contributing Cause Code List was used. Therefore, in some collisions the possibility exists that an equipment failure preceeded an operator error.

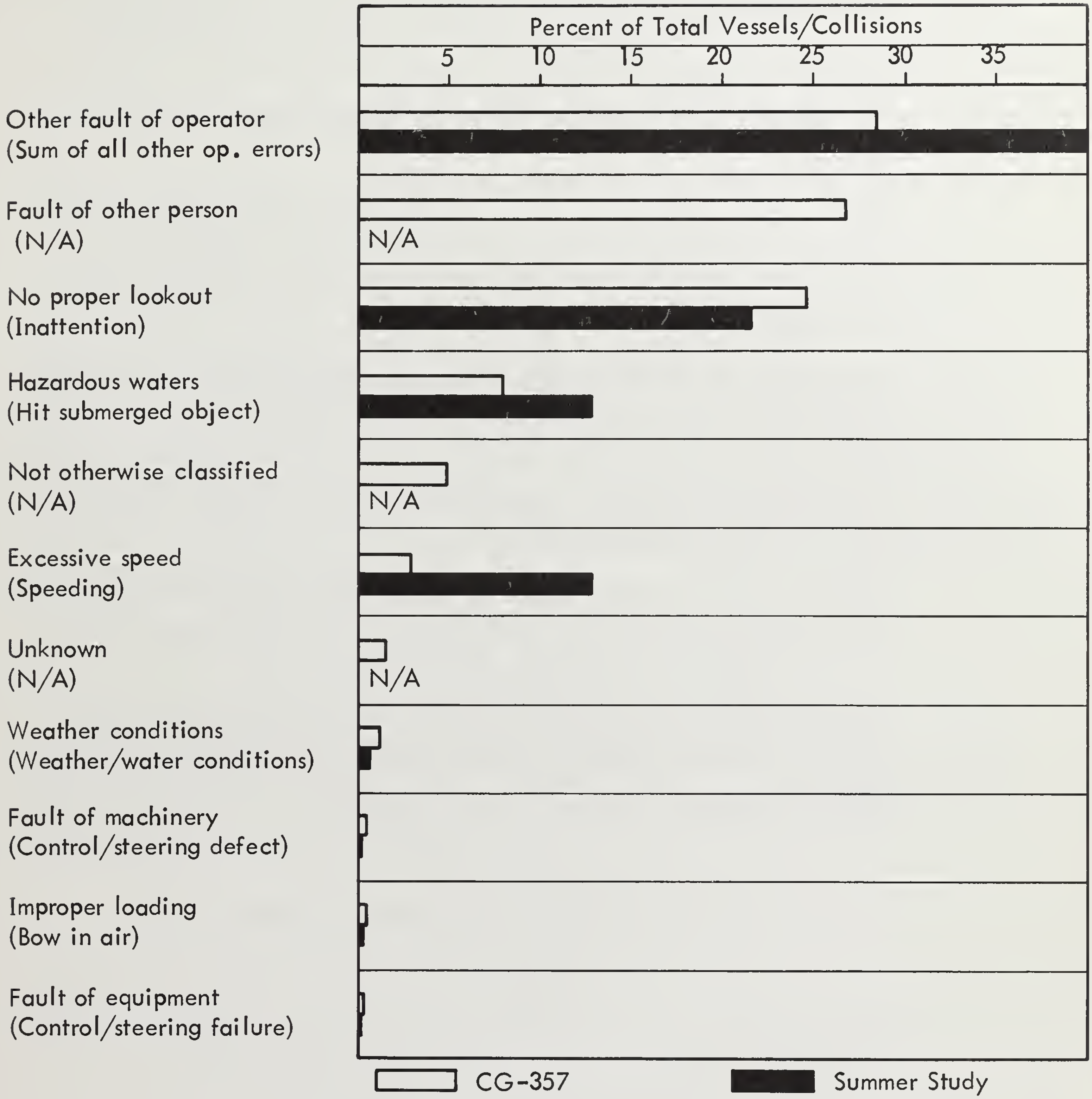


Figure 2-11. Collision Cause Comparison — 1974 Summer Study Vs. CG-357

In summary, the results of the 1974 summer study and the collision information in CG-357 correlated surprisingly well. Some of the more important results are listed below:

- The death, injury, and property damage rates of the summer study were double those shown in CG-357.
- The casualty rate for outboard boats is double that of the next highest category.
- Inboard boats are involved in more collisions than any other type.
- Class 1 boats were involved in more than twice as many collisions as the next highest category.
- The number of two boat collisions is more than twice that of the next highest type of collision.
- The time that collisions occur per the summer study does not follow the time of accident curve in CG-357.
- Operator error accounted for over 90% of the primary causes of collisions with inattention and speeding accounting for 35% of the collision causes.
- Since over 90% of the primary causes were because of operator error and 19% involved rules of the road and navigational errors, thought should be given to education as a means to reduce collisions.

2.5 Collisions At Night

Twenty-one collisions, or 30% of the 69 collisions, happened when it was dark. Although no concrete figures are available, the probability is that the nightime boating activity is less than 30% of the daytime activity. Therefore, the nightime collision rate is probably considerably higher than the daytime collision rate. This is graphically shown in Figure 2-8.

Because of a lack of data it is difficult to estimate the distribution of the number of boats on the water throughout the night; however, it may be assumed that the number of boats on the water would be greatest just after dark and decrease rapidly until about midnight, then pick up slightly just before dawn when commercial fishermen and some serious pleasure boat fishermen are going out. If this is true, the curve on Figure 2-8 showing total boating accidents per CG-357 would tend to follow the boating activity at those times indicating that the rate of collisions throughout the night tends to remain at a higher level that the daytime rate. Therefore, both the percentage of reported collisions during the 1974 summer season and the boating activity vs. time of collisions curve agree that the collision rate at night is somewhat higher than the daytime rate.

2.5.1 Visibility Oriented Nightime Collisions

The causes of the 21 nighttime collisions are predominantly visibility oriented. In fact, 13 of the 21 collisions can be attributed to visibility related causes as detailed below in order of their frequency of occurrences.

LIGHTING PROBLEMS CAUSING COLLISION

Wyle No.	Remarks
27	The operator of a homemade houseboat kept the 360° white light out because it ruined his visibility. A speed boat hit him from the rear. The speed boat driver was sitting on the back of the seat so he could look over the windshield because his own 360° white light created too much glare on the glass.

Wyle No.	Remarks
34	A tug boat hit a runabout that was adrift without any navigation lights. The operator of the runabout had been drinking.
54	A boat anchored with no anchor light was hit by another boat.
67	Two boats, each going about 30 mph, hit head on. One had illegal lighting (no 360° white light) and the other's white light was obscured in the foreward sector by passengers. In addition, the shorelines were filled with bright lights, many of them colored.
86	Two commercial fishermen in two small boats hit each other. Neither boat had navigation lights. The fishermen said they had never used lights.
	SPEEDING RELATED TO VISIBILITY
83	Boat going 50 mph hit a bridge.
102	Boat traveling at about 30 mph rounded a bend and hit an unlighted barge that had drifted across the channel.
106	Boat hit unlighted concrete platform.
112	A boat traveling at about 35 mph ran into the side of another boat. A well lighted shoreline was in the background.
	NAVIGATIONAL ERRORS RELATED TO VISIBILITY
17	Operator mistook jetty intermediate lights with those at the end of the jetty. He ran the boat up onto the jetty.
155	Boat in unfamiliar water traveling at about 25 mph with no chart hit an unlighted buoy and sank.

Wyle No.	Remarks
159	Operator tried to take a short cut between channel entrance buoy and breakwall. The boat hit the wall and sank.

MISCELLANEOUS RELATED TO VISIBILITY

Wyle No.	Remarks
82	An operator drove his boat through a bridge and into mooring cables of a barge. The barge and cables were unlighted.

Lighting related causes were most prominent and directly accounted for 38% of the nighttime visibility oriented collisions. Within the lighting related cause group four of the five collisions (27, 34, 54, 86) occurred because one of the boats had no lights while in the one remaining case (67) the lights were illegal. For example, in one of the cases the 360° white light was illegal because it was mounted inside the cockpit area of a houseboat, and, therefore, it wasn't visible through 360°. The owner never turned it on because it made such a glare on the windshield that he couldn't see where he was going.

The operator of the speedboat that hit him had the same problem. The 360° white light gave so much glare that he couldn't see through it so he sat on the back of the seat and looked over it. By sitting on the seat, the operator obscured his own 360° white light, which was lower than he was and was directly behind him, from anyone in his path.

In at least two of the cases (67, 112) the well lighted shoreline contributed to the fact that the operator of one boat didn't see the boat or object that he hit. This could account for the peak in the collision occurrences around 2200. There is a good probability that lighted shorelines obscured the boat or object that the hittor hit in some of the other cases. However, the information didn't surface during the telephone screening process.

It appears as if the combinations of dark nights, bright colored lights on the shoreline and high speed make it very difficult to see the tiny combination red/green navigation light that may be approaching. To compound the problem an approaching boat on a collision course shows no relative motion, hence its navigation light appears to be motionless, even though the boat could be traveling at a high speed.

All four of the speeding related collisions also involved lighting in that the collision probably wouldn't have occurred if the object that was hit had been well lighted. However, they were classified as speed related since it was felt that the "hittors" were traveling too fast for conditions, and the collisions didn't involve illegal or lack of proper navigation lights.

It is interesting to note that the three navigational error collisions also relate to lights in that two of them involved lighted navigational aids, while one involved an unlighted buoy.

In summary, within the 13 visibility oriented night time collisions, lighting (or lack of lighting) directly related to the cause of 38%, <u>but was a contributing factor</u> in all of the visibility related nighttime collisions.

2.5.2 Non-Visibility Oriented Nighttime Collisions

The causes of the eight remaining collisions that occurred during the night are so varied that no inferences can be drawn, except that they probably could have just as well occurred during the day. Briefly they are as follows:

INATTENTION

Wyle No.	Remarks
35	One cruiser hit another broadside.
81	A runabout ran into and landed on the aft deck of a tug boat.
148	A tug boat went out of the channel and ran over an anchored, lighted, fishing boat.
158	A boat was hit broadside while cruising in a shipping channel.

RULES OF THE ROAD

98	One boat swerved to the left to avoid a head-on collision. The other boat swerved to the right. They hit.

ALCOHOL

Wyle No.	Remarks
72	Two men left a bar and ran their 16' boat into a piling.

2.6 CAUSE CODE LISTS

2.6.1 Cause Code List Critique

Cause code lists had one main problem area. There are too many choices under each category, especially the operator error category where there were 47 choices. One tends to scan the list for relevant causes. When the list is that large, important choices can be missed. After using the cause code list many times, the numbers associated with the most often used causes become memorized. If the investigator or coder is not constantly aware of the potential problem, he will tend to automatically code similar accidents with the same number without thinking it through.

The decision tree or fault tree analysis method of finding the cause of collisions may tend to solve both of the above mentioned problem areas. First, the coder is instructed to step logically through the decision tree. Therefore, at each step he has to make a decision between only several choices as opposed to 47choices. Second, by stepping through a logically organized decision tree, most of the choices are eliminated as one progresses down the tree. This tends to prevent the coder from writing in the most often used number as opposed to thinking out the events surrounding the collision.

The present coding system doesn't take into consideration that in some cases, very little is known about the probable cause of the collision. The causes that the coder may choose are fairly detailed. For instance, one must know quite a bit about the events that occurred just prior to a collision before he may code "operator inattention." Yet this is one of the most common causes that are coded. Is the coder really sure that the operator was "inattentive", or does he only know that the operator didn't see the object that he hit. Who knows how much attention he was paying to his driving task? How much is enough? How many of the collisions coded "inattention" should be coded "other vessel or object was not seen"?

The decision tree concept allows the coder to code to the level of his knowledge, thus tending to eliminate the guesswork.

2.6.2 Cause Coding - Conclusions

Wyle recommends that the Coast Guard seriously consider the use of a decision tree or fault tree approach to the cause coding of boating collisions. It is quite probable that many coding errors could be eliminated with this method since it forces the coder to logically think through the probable causes of each collision. In addition it provides coding steps along the way so that each collision may be realistically coded no matter how much or how how little detail is known about the accident.

In an effort to test the feasibility of the decision tree approach to collision cause coding, Wyle proposes to use this method to code the causes of the 1975 collisions.

2.7 SUMMARY - TASK II

Much effort was spent in screening and investigating collisions throughout 1974. The question now is, "What did we learn ?"

A surprising number of collisions (30 %) occurred at night with the lighting and visibility problems involved in most of them. It appears as if the nighttime collision rate is significantly higher than the daytime rate. Research is needed in the peculiar problems involved in driving and navigating a boat at night and the associated visibility problems related to vessel lighting, navigational aid lighting, shore lighting, etc.

The detailed vessel data from the 1974 summer study correlated surprisingly well with the CG-357 data, meaning that the 55 collisions that were screened probably constituted a reasonable representative sample of all collisions. The only alarming difference in the data was the death, injury, and property damage rate. The summer study showed the rates to be almost twice that shown in CG-357.

The detailed causes of collision did not correlate well between CG-357 and the 1974 summer study; however, both were in agreement that the operator caused about 90 percent of the collisions.

The questions remain, what factors lead to the more immediate reasons (causes) for collisions, and what can be done to reduce the collision rate.

The most common human failure causes were compared to three operator failure categories in an effort to determine what causes operator failure. Did stressors cause the operator to fail, or a lack of education, or was it due to the boat characteristics. Results are shown below:

Collision Cause	Rate of Occurrence (Per Fig.2-9)	Stressor Induced	Lack Of Education	Boat Characteristics
Inattention	22%	Possibly	Possibly	Possibly
Speeding	13%	Possibly	Yes	Possibly
Failure to Turn To STBD.	7%	Possibly	Yes	No
Careless	7%	Possibly	Possibly	No
Navigation Error	7%	Possibly	Yes	No
Rules of Road (Lights)	5%	Possibly	Possibly	Possibly
Alcohol	4%	Yes	Possibly	No
Lack of Caution In Conjested Area	4%	Possibly	Yes	No
Lack of Operator Experience	4%	Possibly	Yes	Possibly
Other Operator Failure	17%	?	?	?

As can be seen stressors and/or lack of education were involved in all of the human failure types of causes. For this reason they will be studied in depth in Task III.

In attempting to determine causes for collisions an interesting problem was noted. When reviewing BAR's at Headquarters, one has problems determining causes due to a lack of information. When screening collisions by telephone it was found that very often the screening process was concluded when enough was learned about the collision to establish a single probable cause. However, problems developed again when collisions were investigated in depth. In this case the investigator had problems determining causes due to the fact that he knew so much about the details leading up to the accident. He found that in no case could a single cause be established for a collision.

The fault tree approach can be of help in both the first and third case. In the first case the coder can descend the tree as far as his knowledge of the collision will allow him. He can stop and code at any level of detail. In the third case the coder can code and weigh as many causes as he desires for any one collision.

The fault tree approach will be used to code the causes of the 1975 collisions in an effort to determine its feasibility as a tool for Coast Guard coding personnel.

TASK III

3.0 TASK III — HUMAN/BOAT PERFORMANCE PROBLEMS

3.1 INTRODUCTION AND BACKGROUND

In Task I the boating accident data collection system was analyzed for the purpose of evaluating and therefore establishing a confidence level in the data handling systems and as a first step in the Collision Research Problem Identification Task. In Task II we became intimately involved with the boating collision problem area by screening and investigating collisions as they happened throughout the summer of 1974, the purpose being to fill in the gaps in the Problem Identification Task.

Task III will take the next step. Given that we think we know something about the causes of collisions, how can those causes be broken down into their elements? In other words, what were the causes of the causes? Perhaps using this technique, basic problems can be identified and some realistic solutions pursued.

The device which most clearly shows the interrelationships of the three tasks of the collision research project is the fault tree of Figure 1-5. This fault tree was developed in the data analysis task to insure that all contributory accident causes are identified. In-depth accident investigation reports will assign weighted causes to the various blocks of the fault tree to identify the primary problem areas.

To show the relationship of Task III to the fault tree, Table I was developed. Based on the preliminary findings of Tasks I and II and using engineering judgment, the boat, operator, and environment causal factors for each block of Figure 1-5 are identified. This table will be modified and correlated with the probabilities assigned to the fault tree in subsequent phases of the research projects.

Each block of Figure 1-5 appears below. Causal factors are applied and the number of times that the block was used to describe the cause of a collision in the 1974 summer study and the first half of the 1975 summer study are noted and totaled for the four major categories.

TABLE I. RELATIONSHIP OF TASK III TO THE FAULT TREE

Category 100 — Other vessel or object strikes this boat/person

Number of Occurances	Block Number	Block Title	Causal Factors
16	C110	Fault of other vessel or object	This operator in no way contributed to the cause of the collision.
2	C111	This person/boat's operator didn't see other vessel/object	In this case it must be evident that this boat's operator was not negligent in his watchkeeping duties.
16	C112	This person/boat's operator saw other vessel/object but adequate response not possible	This person's boat didn't have the power to propel it out of the way of the oncoming boat; he couldn't start the engine in time, etc. It must be evident that slow reaction time on his part or an improper maneuver didn't contribute to the collision.
2	C113	No operator on this boat	It must be evident that the boat was left in a proper anchorage, mooring, slip, etc.; and that it was properly lighted or marked. This block cannot be used for unlighted boats drifting in a channel at night, etc.
1	C120	Fault of this boat's operator	This boat's operator had to have made an error that caused another boat to hit him other than those specified below. The operator may have been fatigued. Education could help prevent such collisions.
4	C121	Improper operating conditions of this boat	This boat may have been adrift at night with no lights showing. It may have been out of control. The operator may have been drunk, or speeding, or not at the helm. Operator fatigue may have been involved. Education could help prevent such collisions.
4	C122	This boat made improper action or maneuver	The operator of this boat could have turned the boat into oncoming traffic, turned left in a meeting situation or made some maneuver without checking for other traffic. Fatigue could have been involved. Education could have helped prevent the collision.

45 = boats involved in collisions where they were hit by another vessel or object.

Category 200 — This boat strikes vessel or object due to fault of this boat's operator

Number of Occurances	Block Number	Block Title	Causal Factors
2	C240	Other vessel or object was not seen	This operator didn't see the vessel or object that he hit before he hit it.
N/A	C210	Couldn't see it	For some reason other than those three listed below the operator couldn't see the boat or object that he hit.
8	C211	Operating condition of this boat	The boat was speeding, the operator wasn't at the helm, bright panel lights obscured his view, the operator was driving at "hump speed" so the bow was high, there was some sort of structure blocking the forward visibility, dirty windshield, etc. Education could have helped the operator avoid the conditions that led to the collision.
3	C212	Other persons or object obstructing view	People forward of operator, movable objects forward of operator.
10	C213	Object or vessel not discernible	Heavy fog, unlighted object or boat at night. This boat going too fast for conditions. Education could help prevent such collisions.
N/A	C220	Didn't see it	He could have seen it but for some reason listed below he didn't see it.
10	C221	Operator inattention	The operator may have been fatigued due to heat, sun, glare, vibration, duration of exposure, alcohol, or sleep deprivation. The operator may have been occupied with activities other than his vigilance task. He may have been turned aft or to the side and may have been talking to other boat occupants or he may have been daydreaming. Education could help prevent such collisions.
11	C222	Object or vessel discernible but didn't see it	It is unknown whether the operator was actually inattentive. However, the thing that he hit was definitely discernable. He could have been fatigued due to heat, sun, glare, vibration, exposure duration, alcohol, and/or sleep deprivation. His boat could have had visibility problems or noise levels could have been excessively high. Education could help prevent such collisions.

Category 200 (cont.)

Number of Occurances	Block Number	Block Title	Causal Factors
N/A	C230	Other vessel or object was seen	The operator saw the other vessel but hit it for reasons described below.
7	C231	Adequate response not possible due to this boat's operating conditions	The operator was standing at a console designed for seated operation and couldn't maneuver the boat adequately, the boat was going so fast that the operator couldn't respond, the boat was out of control, mechanical failure due to improper maintenance, excessive lateral accelerations, other vibrations, etc. Education could help prevent such collisions.
6	C232	Adequate response possible but not made	The operator froze at the wheel, the operator didn't make any response due to fatigue or possibly control station design or visibility problems. Education may help here, too.
15	C233	Improper or inadequate response made	The operator turned the wrong way, made a control manipulation error, didn't turn enough or too much, hit reverse instead of forward due to fatigue, visibility problems or possibly excessive control forces. Education could prevent such accidents.

72 = boats that struck a vessel or object due to the fault of this boat's operator

Category 300 — This boat strikes vessel or object due to causes not the fault of this boat's operator

Number of Occurances	Block Number	Block Title	Causal Factors
4	C301	Operating conditions of other boat	Other boat swerved in front of this boat, backed out of slip in path of this boat, etc.
10	C302	Underwater object	This boat in proper channel or in area with adequate charted depths hit underwater object.
3	C303	Other vessel or object was not discernible	Other boat didn't have lights on.
1	C304	Sudden change in weather or water conditions including wake from other vessel	Wake tossed this boat into another vessel or object, freak act of nature caused this boat to hit another.
0	C305	Design of this boat	Any design fault of the hull or machinery that could have caused this boat to hit another.
0	C306	Inadequate input capabilities of this boat's operator	Too much force required to manipulate the control that would avoid the collision.

18 = boats that struck a vessel or object due to causes not the fault of this boat's operator

Category 400 — This boat strikes vessel or object due to this boat's failure

Number of Occurances	Block Number	Block Title	Causal Factors
1	C401	Fault of this boat's hull	Hull failure causes control problems, etc.
1	C402	Fault of this boat's machinery (engine/ drive train)	Engine stalled causing loss of control, transmission failure, shaft or strut failure, rudder broke, etc.
7	C403	Fault of this boat's controls (shift-throttle-steering)	Steering broke, control cable broke, shift mechanism broke, etc.
0	C404	Fault of this boat's equipment	Compass broke while operating in inclement weather, lights failed, etc.
0	C405	Inadequate output response of this boat	Rudder fouled by debris, propeller fouled, etc.

9 = boats that struck another vessel or object due to this boat's failure

If we go back to our findings in Tasks I and II, we see that people cause about 90 percent of the collisions. The importance of the human factor is also evident in Table I. Boat operators are allegedly inattentive, they speed, they are careless, make navigational errors, drink while driving, and so forth. But what causes them to collide with other objects? What causes inattention? Are there any common elements within the major listed causes of collisions that, if changed or controlled, would reduce the number of collisions?

In order to determine the elements of collision causes and relate them to the overall problem, operator error was broken down into three categories as shown in Figure 3.1.

The psychological stressors category and the boat characteristics category have been studied in depth. The education problem is discussed separately and is also discussed in the Conclusions and Recommendations section in terms of its value as a collision reduction method.

Operator stressors were felt to have had the major impact on operator errors; therefore, most of the effort in Task III was placed on the stressor area. Within the stressor area environmental based fatigue was felt to be of major importance. A study was designed to measure boat operator performance as a function of environment based fatigue in an effort to determine if boat operator performance is actually effected and if so can it be measured. This effort is summarized in Section 3.2 and is detailed in Appendix III-A.

The fault tree approach will be used to code the causes of the 1975 collisions in an effort to determine its feasibility as a tool for Coast Guard coding personnel. This approach will also better show whether or not the remaining portions of the research program are addressing all the problem areas and whether or not the research priorities are properly established.

Equipment based operator stressors were also studied. Actual operator visibility was measured as were control forces, noise levels, and vibrations. Control stations on various types of boats were measured and compared to human engineering standards.

The probable contribution of boat characteristics such as stopping distance and turn radii are discussed, as is alcohol as a stressor. Future work on the effects of alcohol on the boat operators performance is discussed as is the probable payoff of education from the standpoint of collision reduction.

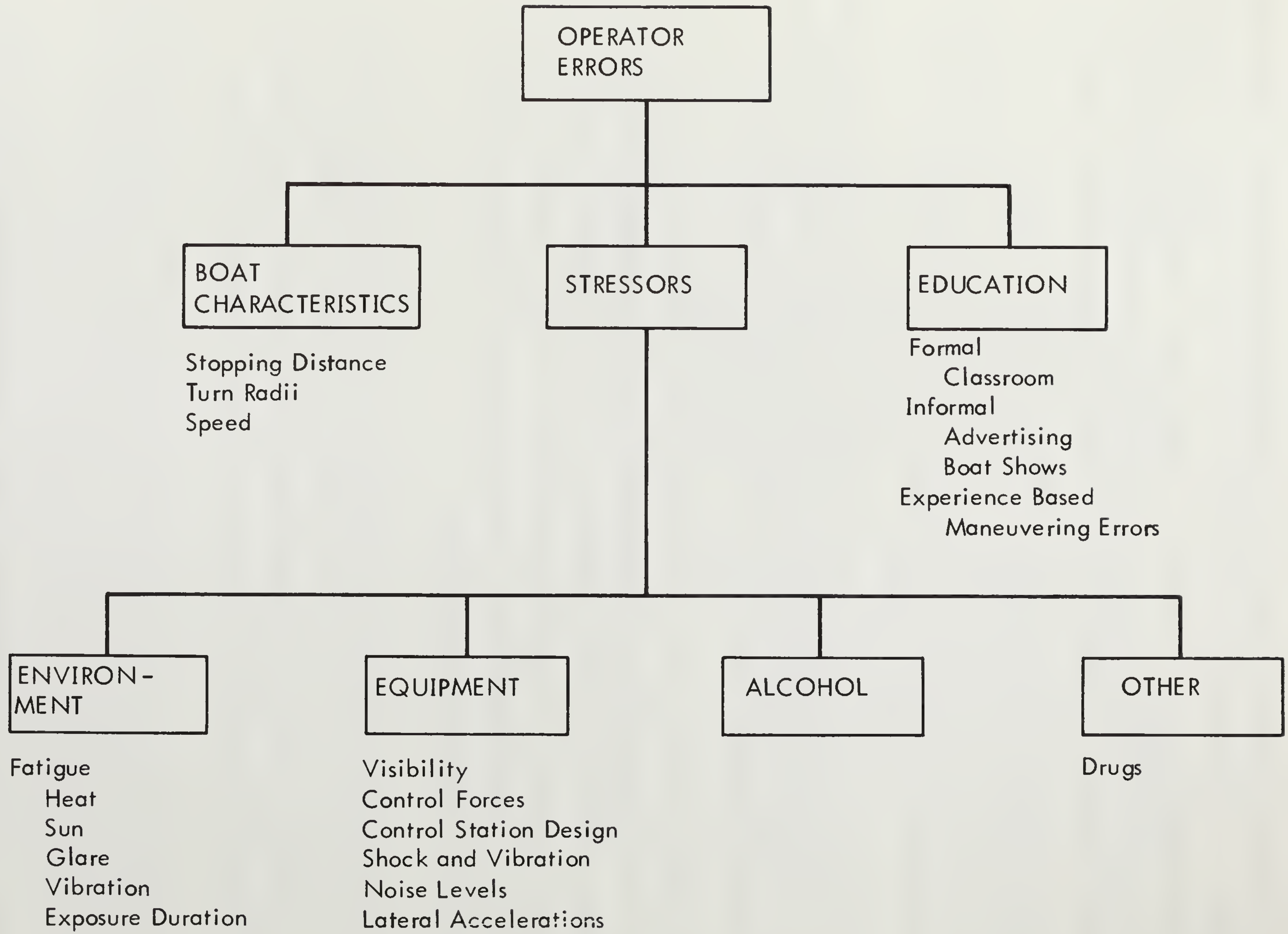


Figure 3.1 Operator Error Categories

3.2 OPERATOR STRESSORS - ENVIRONMENT BASED

There are many factors in boating collisions and accidents. Not the least among these is the boat operator. There are many ways in which the operator is involved, and there are many factors that can affect him. He is exposed to various stressors (glare, heat, fatigue, vibration, etc.). He must make decisions and judgments concerning his boat's operation (speed, distance, course, plan of action, etc.). He must detect and avoid other boats, water skiers and swimmers, and objects in the water. The two previous sections of this report have shown that 60 to 90 percent of the causes of boating accidents are people related. Thus, one of the major thrusts of boating safety research should be at operator problems and stressor effects that lead to potential accident situations. Such a research program should probe stressor effects and operator performance characteristics. The Visual Alertness Stressor Test (VAST) is part of such a program.

Some discussion seems appropriate of what stressors are and what the term "stress" means. In terms of human performance, stress is not something the individual defines, but is a characteristic or set of specifications of the demands placed upon the individual by himself, the task, and the environment. This definition of stress makes it manipulable (an independent variable) and frees the definition from subjective impressions of what is stressful or what is challenging. It is clear from this definition that not all stress leads to performance decrements. Indeed, boredom may be defined as the result of a stressless situation. Thus, optimal performance may be obtained at some intermediate level of stress (church pews may be hard - stressful - merely to keep one awake and attentive). In the boating accident situation, one is concerned with several aspects of stress; principally, task overload (too many boats or too tough boating conditions to operate safely) and environmental stress (alcohol, glare, etc.). However, might we have situations of too little stress (as defined above), boredom, and inattentiveness? These are issues to keep in mind as the research progresses.

Since our present concern is with environmental stress (and task overload to an extent), the critical issues remain of what stressors are causing accidents and how.

Environmental stress can come from various sources and, obviously, higher levels of stress lead to poorer performance. However, we should realize how adaptable man is to stress. The eye and the ear can tolerate changes in intensity and frequency that demand logarithmic scales because of their magnitude, without severely changing man's performance. Man is affected by heat, vibration, glare, etc., but not nearly so easily as computers and other devices of similar complexity. The astounding tolerance of man makes it even more critical that we discover where his limits are. As research continues, we find these limits of performance are often reached before subjective feelings of discomfort are encountered. These are probably the areas of the most difficulty with respect to safety because the individual does not realize he has been influenced and may not realize it even after an accident.

From the psychological studies of stress, a few more generalizations can be outlined. Different sources of stress are typically not additive in their effect, but interactive. This demands that one investigate all stressors in a situation for their individual <u>and interactive</u> effects. For example, studies on information processing have shown that loss of sleep leads to poorer performance and high levels of environmental noise lead to poorer performance. However, when the two stressors were combined, the noise increased the level of arousal, compensating for the lack of sleep, and performance was <u>better</u> than under either stressor alone. The point? Stress should not be considered as a single thing, and stressor interactions should be studied as well as individual stressors.

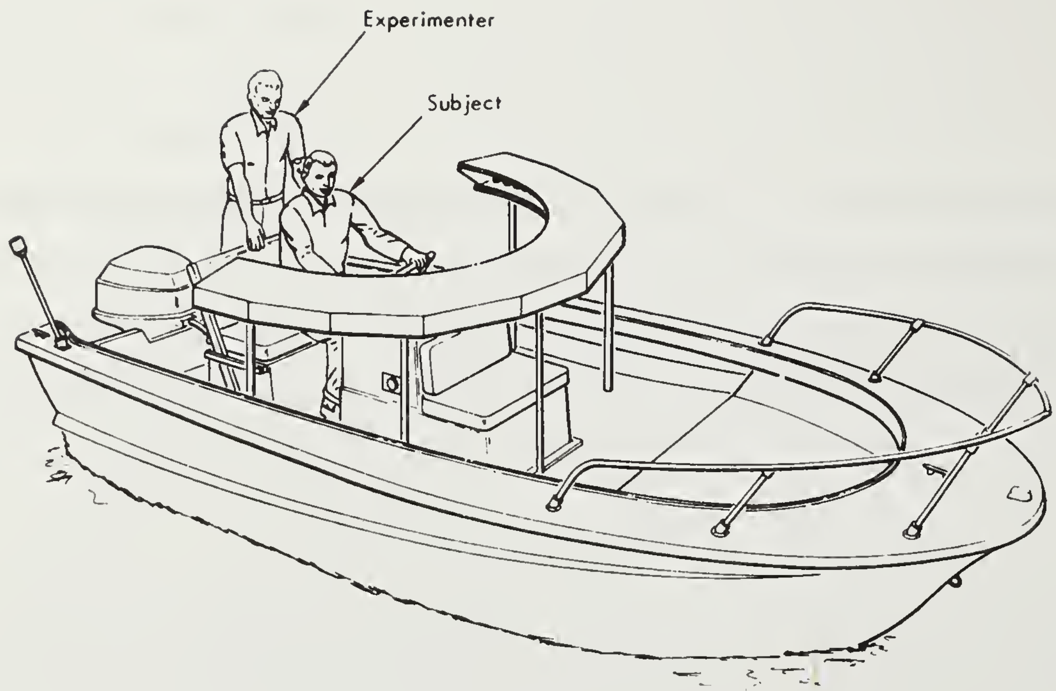
Stress, then, is not a simple idea, but a complex one. The effects of stress are not static, but dynamic; i.e., they change as the task goes on. One formulation of this idea is the Yerkes-Dodson Law, which claims that the optimal level of irrelevant stimulation increases as the level of task difficulty decreases. This suggests, for example, that as one learns a task, he can tolerate more and more stress while maintaining the same level of performance. In fact, more stress may be desirable to avoid boredom after learning. In boating one must separate relevant stimuli such as boats and navigational lights from irrelevant stimuli such as shore lights. How might the Yerkes-Dodson Law apply to fatigue? It would predict that one could tolerate less stress under fatigue than otherwise. Thus, a certain amount of flare may not be a factor when heading out to fish, but <u>a lessor amount of glare</u>, after you've been fishing

all day may be a significant factor. Individual differences are important in stressor effects as well. Of critical importance then is the complex nature of stress and stressor effects, and the ability of the individual to maintain his attention upon relevant information in the performance of his tasks.

The VAST program arose from the need to know whether or not stressors really had an effect on boating performance and safety. To provide that knowledge, the Coast Guard needed an experimental design and a performance measurement device. In the boating environment, performance measures are not as salient as in the automobile arena or other transportation areas. One cannot measure how much of the time a boater "stays in his lane" or how many "red lights he runs." In this type of problem area, the technique of a secondary task or measure has been used for many years. The basic idea is to develop a secondary task, in addition to the one in question, which is sensitive to the manipulations one wants to make. Humans can adequately perform a single task (even one of some difficulty) but may experience trouble when called on to perform two tasks at once. Thus, one can measure the effects of the manipulations on the primary task by the degradations in the secondary task. If performance on the secondary task is degraded due to a factor while the performance of the primary task remains relatively unchanged, then that degradation is a measure of the factor's effect. Often, the secondary task is measured in reaction times, with degradations causing increases in the reaction times on the secondary task.

In boating, the primary task is to safely operate the boat from one place to another. The problem was to come up with a good secondary task to measure the effects of stressors and other factors. In VAST, the secondary task was to respond to certain patterns of lights in a semi-circular display in a bot cockpit, while the primary task was to stay on a specified course.

The VAST experiment set out to determine several things. Principle among these was the issue of whether the entire realm of environmental factors (wind, waves, glare, heat, etc.) combined had a measurable effect upon boating performance. Notably, darkness and alcohol were excluded from the list of stressors. A second major concern was the suitability of the VAST apparatus as a measurement and testing tool in this arena. Was the device sensitive? Did it measure all subjects in a similar way (repeatability)? Finally, could subjects understand the device and operate with it in the experimental paradigm?



EXPERIMENTAL APPARATUS - VISUAL ALERTNESS STRESSOR TEST (VAST)

The VAST apparatus consists of a partial ring of shielded lights at the operator station of a seventeen foot center console runabout, and several response and control devices. The subject's primary task is to steer the boat on a course specified by the experimenter. His secondary task is to respond via a thumb switch on the throttle to appropriate light patterns. In the experiment initially run near Sanibel Island, Florida, the appropriate pattern was any stationary light in the 39 light display. Thus, while the subject tries to stay on course, a minicomputer in the in the bow turns on various light patterns. The subject is supposed to respond to stationary lights only, by depressing a thumb switch on the throttle. The light patterns and the subject's responses are recorded on tape to allow the calculation of the subject's reaction times. Comparisons of these reaction times under various stressors allows the measuring of the stressor effects.

As mentioned earlier, Appendix III-A includes all the details; however, the following is presented as a summary of the experiment and the results.

The experimental design that was used in Florida followed two scenarios of a "typical" boating day. Day 1 was the "family stressors" day. The subjects were asked to engage in preparatory activities prior to the first VAST run that consisted of driving around the island with the boat in tow, and launching the boat. Then the subject went through a one hour test on the VAST boat. The next three hours involved beach activities and lunch simulating family activities (playing catch, shelling, etc.). The subjects were exposed to 10-20 mph winds, glare (no sunglasses), and temperatures in the mid to high 80's. After these three hours, the subjects were tested on VAST again.

Day 2 found the preparatory hour and stressor hours changed slightly. The preparatory hour involved driving only, followed by the one hour VAST test. The three stressor hours found the subjects driving around in boats, drifting in boats, and riding in the bow of the VAST boat for an hour before their second VAST run. These activities were thought to be closer to a fisherman's activities than were those of Day 1.

What were the results? The Day 1 versus Day 2 comparison (type of fatigue) was insignificant. The mean reaction time for subjects on Day 1 was 3075 milliseconds, or 3.075 seconds. The mean reaction time for subjects on Day 2 was 3068 milliseconds, or 3.068 seconds. Since the reaction times ranged from 200 to 20,000 milliseconds, this difference of 7 milliseconds is negligible. The difference between morning and afternoon reaction times was significant, however. The mean for all subjects of morning reaction times was 2131 milliseconds, while the mean for the afternoon trials was 4000 milliseconds, or nearly double the morning times. An F. test (a statistical method for finding significant differences) for differences between means was conducted on the data with the result ($F = +6.62$, $p < .025$) that the difference is statistically very significant. Thus, the combined stressors for three hours caused a large degradation in performance on VAST in terms of reaction times. In terms of errors, there was only one missed signal on morning trials, while there were 10 missed signals on afternoon trials. Again, this illustrates the dramatic combined effect of the stressors. In fact, the experimental results showed that there was a statistically significant increase in the subjects' reaction times on the VAST task under the influence of the combined stressors.

The two important findings of this initial VAST experiment were 1) that the combined day time stressors (heat, glare, noise, waves, etc.) did have an effect on performance, and 2) that the VAST apparatus and experimental paradigm were sensitive to the effect. It should be noted that there is a difference between statistical <u>significance</u> and <u>importance</u>. While there may be a statistically reliable difference in the average distance of a Hank Aaron home run as opposed to a Mickey Mantle home run, the difference is probably not important since the end result of any home run is the same. In the present case, the average difference between rested and fatigued subjects on the VAST task was almost two seconds. The issue now is, is the two second difference important?

The two second difference on VAST may not represent the true magnitude of the stressors effect in "real time." The VAST task is a quick response task. All the subject must do is decide if he has seen an appropriate stimulus, and, if so, push a button. The stimuli are complicated, but simpler than the real stimuli of boats. With the lights, there was no depth perception, no glare on the target, no visual obstructions, etc. The response was also easier. It's certainly much easier to push a botton than to decide upon a maneuver to execute and then do it. Thus, the measured two second difference underestimates the true difference in real time. In addition, a boat travelling 30 miles per hour will travel 44 feet in a second. A time difference of two seconds due to fatigue (which, from the previous discussion, is a conservative estimate) would mean the boat would travel an additional 88 feet before the operator could react. How many accidents might have been prevented or avoided if the operator had reacted 88 feet sooner? Obviously, this kind of a difference could be important.

Of greater importance are the fatigue trials which resulted in the operator missing signals completely. The subjects missed 10 signals in the afternoon and only one in the morning. Thus, the important difference might be the tendency to miss signals (perhaps "miss" another boat) under fatigue. This means not just a delay in the response, but no response at all. The fatigue or stressor effect may be one reason why so many boaters say, after a collision, "I never saw the other boat," or, "He didn't have his light on." The effect of causing the boater to miss signals, or other boats, on the water is very important indeed.

The VAST apparatus and experimental paradigm can be used with any single stressor or combination of stressors. The near doubling of the average reaction time in the present experiment is comparable to the doubling of detection times, eye movement times, and mental processing times found with alcohol levels near 0.10 percent BAC (the generally accepted definition of legally drunk). This suggests that the VAST study should be replicated with alcohol, and two levels of fatigue, to measure the effects of alcohol alone and combined with other stressors. Such a study could result in significant contributions to our knowledge of stressor effects in boating (particularly, alcohol) and to developing a scale of stressor effects by comparing the relative sizes of induced VAST performance degradations as part of Phase II of the collision program.

Specifically, Wyle proposes to do an alcohol study this summer following the general outline in the previous paragraph. The two alcohol levels will be 0.00 percent and 0.10 percent BAC. The two levels of fatigue will be rested and fatigued. These groups of subjects will be run on the same experimental paradigm as in Sanibel: Group 1) will be the controls, with no alcohol, Group 2) will be given alcohol before the morning (rested) test and their data will be compared with the morning (rested) data from Group 1 to determine the effect of alcohol alone, Group 3) will be given alcohol before the afternoon (fatigued) test as an additional stressor. Their data will be compared with the afternoon (fatigued) data from Group 1 to determine the interactive effects of alcohol with the other stressors. Wyle is considering using a placebo condition for Group 3's morning tests to investigate the social/psychological effects of drinking (as opposed to the effects of alcohol per se).

Further studies are in the planning stage to isolate other stressors such as noise, glare, and heat. For some of these (noise, for example), laboratory studies may be needed to define appropriate stressor (noise) levels for the follow-up field studies. These experiments will involve some modifications to accommodate particular stressors, but the basic VAST experiment can be run to determine the stressor effects. Thus, VAST is applicable in many of the areas where collision research is needed.

3.3 STRESSORS - EQUIPMENT ORIENTED

The fact that rather extensive safety standards exist for operator visibility, noise, vibration, and control station design parameters in the automotive industry, the aircraft industry, and the military, emphasizes that equipment oriented safety enhancement concepts are important. Therefore, the importance of equipment oriented stressors will not be labored upon. Instead, the assumption will be made that the operator fails because of the interaction of many stressors and with the exception of isolated instances the elimination or reduction of these stressors will have a beneficial effect on his level of fatigue and, hence, his chances of detecting a dangerous situation and avoiding a collision.

The major effort in this portion of Task III has been to record the results of known studies related to dynamic boat parameters, measure parameters where information was unobtainable, relate them to human performance capabilities, determine if the stressor level of the measured parameters were at a level that could cause performance degredation, and document the results.

Areas covered in this section include:

- Visibility
- Control forces
- Lateral accelerations
- Noise levels
- Shock and vibration
- Dimensional characteristics of control stations
- Space envelope development

Boat characteristics such as stopping distances and turn radii vs. speed are covered in Section 3.4.

3.3.1 Visibility

3.3.1.1 Introduction

James M. Miller, Ph.D., University of Michigan, defines and discusses the visibility problems in-depth in his "Human Factor Applications in Boating Safety" (Reference 2). Rather than repeat what has already been said, this discussion will pick up where he left off in that it will be directed more to the practical side of the problems rather than the theoretical.

In order to avoid a collision, the boat operator must be able to see out of his boat. He has to be able to see objects and persons around him well enough to be able to make certain judgments about actions to be taken. From the collision standpoint, the operator must decide if his boat will hit something as it travels along the intended path, or if another boat will hit him if the two boats continue to travel in the same direction and speed.

Obviously forward visibility is most important. To avoid colliding with an object in front of him, the operator must be able to see the water over the bow, cabin top, or other obstructions. He must also be able to see under the upper windshield frame or cabin top to avoid hitting overhead obstructions. The distance in front of him that he can actually see the surface of the water determines the size of the object that he can see. Some objects that are undiscernable at 200 ft can easily be seen at 20 feet. After sighting the object and determining what it is, the operator must decide if he wants to avoid hitting it. Present industry standards, present boat building practices, people sizes, etc., all play a part in the forward visibility problem and will be discussed in-depth as part of this task.

Visibility to the side and aft are of lesser importance than forward visibility but, nevertheless, are necessary for safe boat operation. The operator must be able to see moving objects on both sides of his boat in order to determine if those objects may move to a position in front of him and thus pose a threat of collision. Although rear visibility is important from the standpoint of overall operator vigilance and navigation, it is most important while docking or maneuvering in close quarters.

3.3.1.2 Power Boats - Visibility Problem Areas

Power boats tend to have inherent common problems that restrict or limit visibility. Sailboats tend to have different visibility problems, which will be discussed later.

3.3.1.2.1 Windshields — In most powerboats other than open fishing boats, the operator must look through a windshield. Visibility problems occur from the degradation of the operators ability to detect visual targets through the windshield due to glare, reflections, foreign matter on windshield surfaces and tinting. Window frames and other structural obstructions further limit visibility.

The automotive industry has done much to reduce the effects of glare and reflections on automotive windshields. The recent trend towards gray or black windshield wiper brackets, the general trend towards black or dark colored textured horizontal surfaces between the base of the windshield and the instrument panel, and the elimination of the use of chrome on parts of the instrument panel, radio speaker, steering wheel, or any other item that could reflect onto the windshield are all examples of their efforts.

Unfortunately, the boating industry as a whole has done little to solve the glare and reflection problem. Some large power boats, mostly the commercial boats, have slanted the windshields forward at the top. This, coupled with a cabin top overhang, almost eliminates the glare and reflection problem. But a "reverse slant to the windshield "visually slows the boat down" from a stylists viewpoint, therefore, one almost never sees reverse slanted windshields on pleasure boats.

Deck surfaces are generally fiberglass and have the same surface color and texture both forward and aft of the windshield. The color is generally white or a light tint and the surface is generally smooth. Good arguments can be made for these decisions, such as, white surfaces are coolest in the summer, smooth surfaces are cheapest to produce in fiberglass and are easiest to clean, however, some thought should be given to the glare and reflection problem.

Since the angle of reflected light off a surface is equal to the angle of incidence, it is not too difficult to design for glare and reflection reduction, if the drivers eye position is known and the area of eye positions is small. However, the boat drivers position varies widely and

therefore, so does the drivers eye positions. This makes it almost impossible to eliminate direct or specular reflections from reaching the boat drivers eyes. However, the addition of a non-gloss, textured, medium to dark colored surface aft of the windshield would go a long way to reduce the problem.

Table II below shows the approximate reflectance factors for various surface colors:

TABLE II. APPROXIMATE REFLECTANCE FACTORS FOR VARIOUS SURFACE COLORS *

Color	Amt. of Reflected Light (%)	Color	Amt. of Reflected Light (%)
White	85	Green	
Yellow		Light	65
Light	75	Medium	52
Medium	65	Dark	7
Buff		Blue	
Light	70	Light	55
Medium	63	Medium	35
Gray		Dark	8
Light	75	Red	
Medium	55	Dark	13
Dark	30	Brown	
		Dark	10

*From Woodson, W.E. (1954) "Human Engineering Guide for Equipment Designers" (Univ of Calif. Press, Berkeley, Calif.)

It is obvious that visibility will be impaired if the driver must look through a dirty, clouded, rain or spray soaked windshield. Windshield surface cleaning prior to boat usage is a problem of housekeeping. The operator has total control over this problem area. Steamed up windshields have always been a problem with cabin cruisers. Unfortunately, the boating industry does not provide defrosters for windshields.

Windshield wipers are optional equipment on most runabouts and small cruisers and as such are afterthoughts. Windshield wiper motors frequently are so located that they obstruct the view of the operator. Figure 3-2 shows the wiper motor on a Coast Guard patrol boat. In

this case, both the windshield and the wiper were afterthoughts in that they were not designed as part of the original boat. If the motor were located in the corner or at the bottom it would be out of the operators line of sight. In addition, the wiped area would be bigger, giving the operator better foul weather visibility.

Salt spray clouds the windshield and is very difficult to get off without the use of a fresh water rinse. Windshield washers have been standard on automobiles for some time, but are included on only the most expensive large cruisers. Since fresh water is carried anyhow on virtually all boats with galleys, the addition of washer hardware would have a minimal impact on overall boat cost.

Some of the manufacturers of more traditional cruisers and some manufacturers of top quality boats have solved the through the windshield visibility problem by making the portion of the windshield directly in front of the helmsman hinge or slide out of the way. This helps when the visual task is acute, but when the weather is severe the helmsman must decide which is more important; optimizing visibility and allowing the adverse outside elements to enter the cabin area, or keeping warm and dry at the expense of visibility.

The cabin windows of many contemporary boats are tinted. Tinting is used on cabin cruisers as a method to help keep the cabins cooler in the summer, which helps the cabin air conditioners do their job. Tinted windshields on runabouts are in vogue from the stylists standpoint. While tinted glass does absorb some infrared radiation, it also reduces the effective luminence of all visual targets, thus making the helmsman's visual task more difficult. Auto manufacturers have tinted the windshields darkest at the top, leaving the main viewing area either free of tint or with just a slight tint. USAS Z26.1 "Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways"(Reference 3), Paragraph 5.3.2, specifies that windshields and windows for use at levels requisite for driving visibility in the motor vehicle shall show regular (parallel) transmittance of not less than 70 percent of the light at normal incidence. SAE J100 (Reference 4) defines the boundaries of shade bands on vehicle glazed surfaces.

The visual task of the pleasure boat operator is probably more difficult than the visual task of the car driver, especially at night. Therefore, the boat windshield should be tinted no darker than the automobile windshield and probably should be somewhat lighter in tint. (See also Miller, Vol. II, page IX-23 thru 25.) Reference 2.

The light transmission properties of tinted plexiglass are shown in Table III below.

TABLE III. VISIBLE LIGHT AND SOLAR ENERGY TRANSMITTANCE OF THE PLEXIGLAS SOLAR CONTROL SERIES

Plexiglas		Transmittance	
Color	Number	Visible Light	Solar Energy
Neutral Gray	2538	16 %	27 %
Neutral Gray	2537	33	41
Neutral Gray	2094	45	55
Neutral Gray	2514	59	62
Neutral Gray	2515	76	74
Bronze	2370	10	20
Bronze	2412	27	35
Bronze	2404	49	56
Bronze	2539	61	62
Bronze	2540	75	75
Colorless Plexiglas		92	85

Based on the premise that the light transmission properties of boat windshields should be no lower than what is acceptable for automotive use, only Tint 2515 or Tint 2540 should be used. Note that the visible light transmittance properties of the other tints fall well below the 70 percent transmittance factor specified in USASZ 26.1 (Reference 3). Also note that there is a 16 percent degradation between the transmittance factor of clear plexiglass and the lightest tint. Unfortunately, a walk through a boat show will reveal that all tints shown in Table II are currently being used for windshield material by boat manufacturers.

Figure 3-2. Wiper Motor Caused Visibility Problem

3.3.1.2.2 Pillars, Posts, and Windshield Frames — Boat operators are forced to look around more obstacles than automobile drivers. Many windshields are divided into several pieces. Each facet is surrounded by a frame. Windshield frames on cabin cruisers generally help to support the cabin top and flying bridge. They must be sturdy. Mechanical cables and electrical wires must interconnect the lower and upper control console. A housing or tube of some sort to carry the cables is generally located forward of the helmsman. In addition, many boats have a bow rail so located that it obscures a portion of the water forward of the bow. Bow rail support posts as well as pennants or burgees with their support posts also add to the obstructions in the operators field of view.

Figure 3-3 shows the visibility conditions of a boat that was involved in a collision where the operator claimed that he never saw the boat that he hit (reference Case No. 6, Volume II, this report). It is interesting to note that he was heading southeast into the morning sun (lots of glare) and into a one to two foot chop on a coastal bay (lots of salt spray on the windshield). The windshield was tinted quite dark (loss of light transmission through windshield), and was not equipped with a windshield wiper (no way to get rid of the salt spray). The windshield itself was a three piece unit with the largest section in the middle. Since the operator sat to starboard, he had to look through a fairly small opening surrounded by aluminum window frame extrusions (field of view obscured by frames). A chrome bow rail was in his field of view (visual obstruction plus glare) as was a chrome searchlight (again, visual obstruction plus glare). Is it any wonder that he didn't see the other boat?

3.3.1.2.3 Other Objects in the Field of View — Boat manufacturers as well as owners tend to mount large objects to the boat forward of the helmsman in such a way that some portion of his forward field of view is obscured. Bass boat manufacturers mount plush, high backed upholstered armchairs on pedestals forward of the control station. If the chair is turned sideways and locked, the operator can gain visual access to the water on the other side of the back of the chair by moving his head back and forth. However, if the chair is facing forward, as it would be naturally if the brake weren't tightened, some portion of the operators forward field of view is permanently obscured. See Figure 3-4.

Note how windshield post, dark tinted windshield and rail obscure view. Operator's head almost invisible.

Figure 3-3. Visibility Problems

Figure 3-4. Visibility Problems - Bass Boats

Cruiser manufacturers and owners very often mount dunnage boxes on the foredecks to store fenders, lines, anchors, etc. Quite often the boxes restrict the field of view from the lower control station. Owners mount radar receivers, chart type depth recorders, and other large electronic gear on the deck area foreward of the control station. Many times these units obstruct forward visibility. Airplane manufacturers provide spaces within the control panels for this type of equipment. Boat manufacturers on the whole have not advanced to that level of sophistication.

In general, both boat manufacturers and owners often install large objects within their foreward field of view, making a sometimes difficult visibility task even more difficult.

3.3.1.2.4 People Obstructing the View — Small outboard powered boats are steered directly from the motor which is secured to the transom. The driver sits on the rear seat with his passengers sitting on forward seats to balance the live load. Obviously, the driver's forward visibility will be impaired by the people sitting in front of him. In order to better utilize the available space in runabouts, many boats are now designed with seats in the area forward of the driver and windwhield. In effect, this puts the same burden on the driver. He has to look around people sitting in front of him to see the water ahead.

Figure 3-5 shows four bowrider boats with people forward. In the top two photos, the operators are seated and in the case of the boat on the right, the seated operator probably cannot see the horizon over the bow. The operators in the bottom two photos are standing and looking over the heads of the people sitting forward. When there is no top as is the case with the boat on the bottom left, the operator may stand directly behind the wheel; however, notice that the operator in the boat on the right is standing in the middle of the boat with the upper portion of his body protruding through the opening in the center of the canvas top. The problem here is not one of visibility. In fact the operator has compromised other safety aspects in order to gain visibility. By standing in the middle of the companionway, he has moved completely away from the control station. From that position the shift and throttle controls cannot be reached. If the situation developed wherein he had to maneuver quickly in order to avoid a collision, he would have to first duck down and under the canvas top, sit behind the wheel or reach across the seat to manipulate the control handles. When

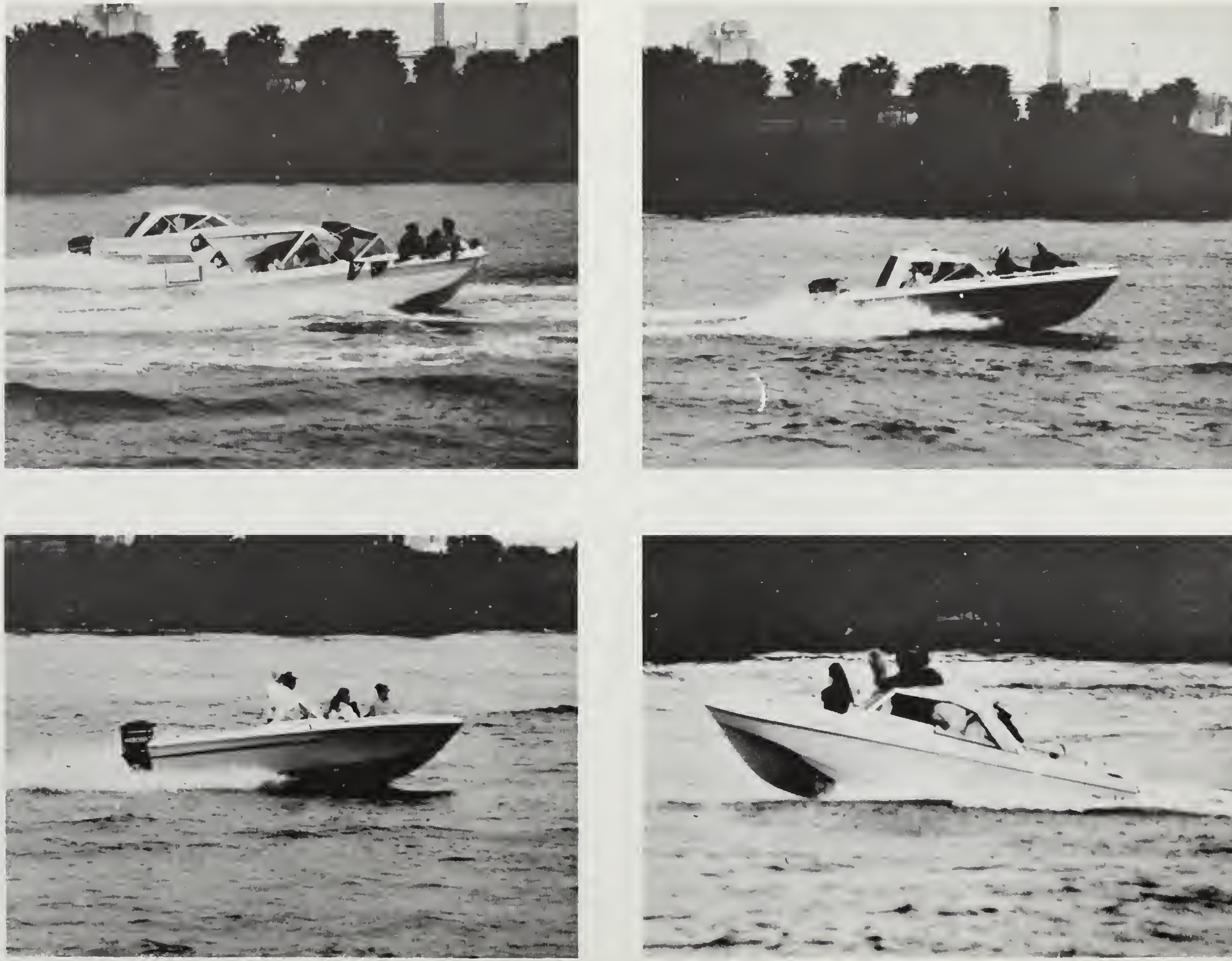


Figure 3-5. Visibility Problems - Bowriders

seated at the console, he would no longer be able to see where he was going.

3.3.1.2.5 Canvas Tops and Sides — Canvas tops and side curtains also limit the helmsman's visibility. Runabouts with center opening walk through windshields have an inherent special problem. When running with the top up and the windshield open, the center section of the top often hangs down, especially if the zippers are partially opened. Quite a bit of side visibility can be obstructed. In addition, the unsupported section will tend to flap about. It is possible that the driver's visual attention may be diverted from the horizon scanning task by the flapping of the canvas.

Side curtains create other sorts of visual problems. Being made of clear flexible plastic, they are not flat when installed. The wavy surface distorts the view somewhat making target identification more difficult than normal. Since side curtains are stored away for most of the time, they tend to quickly become scratched. Since they are used only in inclement weather or when the boat is stored, they tend to become covered with spray (sometimes salt spray) and dirt (from storage). On nice days when the owner is in the mood to clean up his boat, the side curtains are stored away and forgotten. But during inclement weather, when the driver's visual task is most difficult, he is forced to either get wet and cold if he doesn't install the side curtains, or be forced to look through dirty, scratched plastic.

Again, the boat driver's visual task which is probably more difficult than the automobile driver's task, becomes even more difficult because of the characteristics of the design of his boat.

3.3.1.2.6 Planing Boat Transition Stage (Hump Speed) — The temporary high pitch angle that many planing boats achieve while going from displacement speed to planing speed can certainly be classified as a visibility problem area. In many boats, visibility from the seated helm position is totally obscured while travelling in this mode. Sometimes, standing behind the wheel while in this mode will maintain forward visibility; however, in some cases a canvas top over the cockpit area makes standing impossible. In that case forward visibility is obscured for some period each time the boat is brought up on plane.

Many boat operators scan the waters ahead then quickly advance the throttle to get "up and over" in the minimum amount of time. However, in many cases people operate their boats at this awkward attitude for considerable periods of time. Notice the bottom right photo in Figure 3.5. Here the canvas top has an opening for the driver to stand in; however, consider the magnitude of his visibility problems if he were seated behind the wheel.

3.3.1.3 Sailboats - Visibility Problem Areas

Visibility problem in sailboats stem from four major areas, boat attitude, helmsman task loading, operator position on the boat, and sail obstructions. In some cases they are momentary in nature, in other situations, they tend to be of longer duration. To the inexperienced sailor they are unpredictable. For instance, a nearby boat may be in his view at one instant. A change in sail trim could completely obscure the boat for some length of time. Obviously a course change by either or both boats could result in a collision. The following dissertation looks at the four visibility problem areas in detail.

3.3.1.3.1 Sailboat Attitude — The heeling tendency of a sailboat causes visibility problems for the helmsman.

Since severe heeling on a sailboat is generally associated with high wind velocities, and high wind velocities are associated with rough seas and difficult boat handling characteristics, the level of difficulty of the operator's task increases rapidly in proportion to the heeling angle of the boat. In more severe cases, the major portion of the helmsman's task may be to maintain his own balance as well as to attempt to maintain some sort of control over the amount of wind being spilled from the sails to limit heeling angle.

Add to this the facts that people are conditioned to operate on level surfaces, and cockpits are generally designed for level boat operation, it becomes reasonable to assume that during high heeling conditions a good portion of the helmsman's attention could be diverted from his basic vigilance task to one of capsize prevention.

3.3.1.3.2 Helmsman Task Loading — As discussed above, the helmsman's task loading tends to become greater as weather and water conditions become more severe. Therefore, the amount of time he can allot to his vigilance task is inversely proportional to his task loading.

Unlike powerboat operators, the sailboat helmsman often has many more tasks to perform than just steering. Generally his task load increases drastically just at the time when target detection and avoidance are most critical as in turning.

Turning in a powerboat is a simple maneuver. One determines the new direction and the approximate path of the boat and checks for obstructions in that path. One also checks for moving obstructions such as other boats that may be a threat. Then the wheel is turned and the boat is on the new heading.

On the other hand, turning a sailboat at minimum requires sails to be repositioned and many times sails must be taken down and replaced with others when the boat reaches its new heading. On some boats, standing rigging like running backstays must be manipulated at the proper instant of time, or spinnaker poles must be removed from one corner of the sail and replaced on the opposite side of the boat. Vangs must be adjusted, or removed and replaced, traveller stops adjusted, sheets eased or trimmed, and cunninghams, down hauls, outhaul and barber haulers adjusted.

Turning becomes a complicated tactical maneuver that requires the coordination of helmsman and crew. In small boats with small crews, the helmsman's capabilities can become severely taxed. Prior to the turn, the helmsman may be concentrating on the preparations for the turn rather than his vigilence task. Certainly, during the turn, he must concentrate on equipment adjustments and crew coordination. It is not until after the turn has been completed that he has time to look around to see if he is in danger of hitting anything.

Turning is not the only maneuver that requires increased helmsman task loading, changing wind conditions require sail trimming and at times sail changing. The helmsman must always be alert to the configuration of the sails and the "feel" of the helm. Subtle changes can mean great variances in boat speed. Therefore, unlike the powerboat operator who must occasionally monitor engine gauges, the sailor must constantly evaluate sail shape and tiller or wheel pressure in order to maximize boat performance, which could tend to detract him from his primary vigilance task.

<u>3.3.1.3.3 Operator Position</u> — Traditionally, cruising sailboats are "driven" from the aft portion of the cockpit located in the aft portion of the boat. The helmsman must look over

or around his crew, the cabin, the mast and rigging, and any deck mounted hardware such as dorade boxes or dinghys. One of the reasons he was located aft was because sailors have felt that it is more important to have good visibility of the sails than good forward visibility. Recently a trend has developed towards center cockpit, aft cabin cruising sailboats. The helmsman tends to have better forward visibility over the bow in this type of boat since he is located higher and closer to the longitudinal center of the boat. Dinghys and other large objects can be stowed aft giving even better visibility.

Small boat sailors tend to have different operator position oriented visibility problems. The ballast used to counteract the heeling force of the wind on the sails is generally human ballast. That is the helmsman must "hike" out to windward to keep the boat upright. Many times he is in a horizontal position lying just above the surface of the water with only his legs inside the boat. In other cases the helmsman attaches himself to a "trapeze" or wire extending down from the mast. He then can swing out so he is laying parallel to the surface of the water but completely outside the boat.

Obviously the vigilance task becomes less important than one of balance, boat and sail handling and basic survival since even a slight reduction in wind pressure on the sails will result in a dunking for the helmsman.

Large boat sailors that are really interested in getting the most speed out of their boats very often sit on the lee side of the cockpit where the visual access to the "slot" between the Genoa and Mainsail is optimum. If they happen to be sailing a cruising sailboat, with a Genoa in a wind strong enough to heel the boat more than slightly, their forward and side visibility is almost completely obscured by the sail. Visibility to windward is obscured by the boat itself as it heels.

He can't see forward or leeward because of the Genoa. Therefore, an observer sitting to windward must keep the helmsman informed of objects or boats in his path and the best course of action to be taken. See Figure 3-6.

Cruising sailboats are often outfitted with "dodgers." These are small canvas folding hoods that attach to the cabin top forward of the companionway hatch and extend aft to cover the hatch and often some portion of the cockpit. Their purposes are to reduce the amount

Figure 3-6. Visibility Problems - Sailboats

of spray entering the cockpit and to cover the companionway hatch so it can be left open in inclement weather. However, the helmsman must look through and around the dodger. The forward face of dodgers are made of clear flexible plastic and as such are subject to the visibility problems associated with side curtains and discussed in 3.3.1.2.5 above. Obviously windshield wipers won't work on flexible plastic, and since dodgers are primarily used during inclement weather, the helmsmans visibility is, again, significantly impaired by boat hardware at a time when the vigilance task is most difficult.

3.3.1.3.4 Sail Obstructions — The fact that the helmsman couldn't or didn't see a boat or object located on the other side of one of his sails accounted for three of the four collisions involving sailboats in the 1974 summer study.

Sailboat size doesn't seem to matter. The sails of the day sailers and large cruisers obstruct visibility. However, size of boat does influence which sail(s) obstructs the view.

Small boats such as the Sunfish and Laser have only one sail, however, the boom is so low that one cannot see under it while sailing in a normal seated position. In high wind conditions, it is often impossible for the helmsman to move into a position to see under the boom, because in doing so he would change his center of gravity and hence the righting moment of the boat so much that it would capsize. Collision No. 104 occurred because of that reason.

In sailboats larger than approximately 20 feet, the boom is usually positioned high enough over the cockpit to allow the helmsman to see under it under most conditions. There are two types of exceptions: (1) large racing sailboats sometimes have very low booms to maximize the "end plate effect" of the wind on the deck. Examples are the Star and the 12 Meter boats. (2) High heel angles when sailing off the wind dips the end of the boom into or close to the water. The mainsail then obscures the area of water beyond it.

The headsails and specifically the Genoas of large sailboats are often designed to almost touch the deck when the boat is tacking close to the wind. Since the No. 1 Genoa often extends to or even past the forward portion of the cockpit, helmsman visibility is again severely limited. Collision No. 85 happened because two large sailboats were on converging courses but were both obscured from the helmsman's view by their large Genoas. Figure 3-7

Figure 3-7. Visibility Problems - Sailboats

Figure 3-8. Visibility Problems – Sailboats

shows a cruising boat heading more or less towards the camera. It is interesting to note that the helmsman is not visible from a position forward of his boat. Therefore, he can't see forward. In fact, there is a "bow watch" stationed forward to warn the helmsman of impending dangers. Also see Figure 3-8. Here, a crew member has lifted a portion of the Genoa to look for other boats.

Although the visibility is better over the center cockpit boats as opposed to the more traditional aft cockpit boats, their visibility past or around the Genoa tends to be worse. The cockpit is inherently higher, therefore, the chances of seeing under the Genoa is greatly reduced. The fact that the helmsman's location is further forward compounds the problem since it places the leech of the Genoa farther aft in relation to him. Therefore, there is a larger angle of obscured visibility. Some boat owners have actually cut off the bottom of their genoas so that they can see under them. Notice the visibility of the helmsman in Figures 3-9 and 3-10. As can be seen, if the forward corner of the genoa were at deck level, the boat crossing in front would not have been seen.

3.3.1.4 Visual Task

In Section 3.3.1.1 the visibility problems inherent in various types of pleasure boats were discussed. However, until the pleasure boat operators' visual tasks are defined, it will be impossible to assess the impact of the equipment based visual handicaps on probable safety problems and specifically on the collision problem.

Generally speaking, the operators' task is to safely maneuver the boat from one specific spot to another. He must manipulate the controls in such a way that the boat moves away from the area where people ingressed, and towards the desired destination. Controls must then be manipulated in such a way to make the boat come to rest at a predetermined spot on the water.

Miller (Reference 2) defined the visual piloting task as follows:

> "It is first useful to subdivide the general task of piloting into several discrete piloting modes. At least five such modes exist: (we added the 6th)
>
> - DOCKING is characterized by a planned soft collision contact or near collision contact with some fixed target: usually a dock, piling, boat trailer, or beach.

Figure 3-9. Visibility - Sailboats

Figure 3-10. Visibility - Sailboats

- (MANEUVERING is characterized by changing direction and speed often in an effort to avoid obstructions, both moving and fixed. NOTE: This mode was added to Miller's list.)

- CHANNEL OPERATION is characterized by a direction of travel parallel to the channel except where navigable water is present to either side of the channel.
- INLET OPERATION is characterized by a need to observe sea conditions both ahead and behind the craft.

- OPEN WATER OPERATION is characterized by non-stationary visual targets and a vigilance type situation where important targets may occur infrequently and at unexpected times.
- WATER SKIING is characterized by the requirement for a greater lateral and rearward field of view.

The temporal and spatial characteristics of each of these piloting modes place restrictions upon: (1) maneuvering, (2) direction of travel, and (3) velocity of travel.

Three types of visual targets may be encountered within the above six modes of piloting:

- Targets necessary for basic control and navigation may include shorelines, sea conditions, docks, pilings, buoys, daymarks, and lights.
- Regulatory or informational targets might include daymarks or flags such as diver's flags.
- Collision hazards could include swimmers, divers, water skiiers, other craft, docks, pilings, buoys, daymarks, and obstructions protruding above the surface.

The importance of these visual targets are dependent upon: (1) the frequency with which they occur; (2) their accident risk potential; and (3) their accident severity potential."

In order to be able to see the three types of visual targets, the operator should have visual access to the water in front of him, the horizon for some arc around him, and overhead to some extent to avoid bridges, overhanging tree limbs and other obstructions.

3.3.1.5 Variables

3.3.1.5.1 Boat Types — For the purposes of discussing the visibility problems, power boats can be divided into four catagories, depending on where and how the boat is controlled. The catagories are:

- Direct steering - The operator sits aft and controls the boat by moving controls located on the outboard engine. All passengers and gear must be located in front of the operator.
- Runabout - The operator sits at a control console that basically resembles that of an automobile. The seat is generally low and the wheel is so located that the operator's legs pass under it. Bow riders, many bass boats, and most flying bridges on large cruisers fall within this catagory.
- Center console - The controls are located on a console in such a position that they may be operated from a standing or sitting position. Generally, the wheel is similar to the runabout style and is located on a slanted surface on top of the console.
- Cruisers - The controls are generally located on the main bulkhead at the forward end of the salon or deck located directly over the engine compartment. On large cruisers, the controls may be located on the aft main bulkhead. In either case, the operator may operate the boat from a standing or sitting position. Large diameter wheels are generally mounted vertically on the bulkhead. Other controls and displays are generally located on the deck forward of the wheel.

3.3.1.5.2 Control Station Variables — The automotive and aircraft industry have design and performance standards that assure adequate visibility from those vehicles. But the driving position is standard. The automobile driver and aircraft pilot sit in one spot at a relatively standardized control console with all controls within easy reach. The cockpit area is so

confined that they can't stand up or move out of the designed sitting area. Visibility parameters are, therefore, easy to calculate and control.

The driving positions of a boat is not so well defined. Any one particular size or type of boat could concievably be designed to be controlled from the bow, stern, center, starboard, or port side while standing, sitting or kneeling.

As mentioned above, the consoles of many boats are designed to be used while sitting or standing. Many traditional cruisers are designed to be steered from the standing position only. A seat, if provided, may be some distance from the helm.

3.3.1.5.3 Operator Variables — The location of the operator's eyes due to the differences in the sizes of the men, women, and children that may drive the boat can vary quite a bit and must also be considered. Anthropometric data exists on seated and standing people of both sexes and should be used in calculating the visibility from a given helm location on a given boat.

3.3.1.6 Practical Aspects

The many problem areas of different types of boats have been discussed above. They boil down to one basic problem: the operator must be able to see where he is going in order to operate the boat safely.

First, he must be able to see over the bow of his boat to some point ahead of him on the water. But, how far ahead on the water surface should he be able to see? ABYC has recently revised their visibility standard for small craft. They state that the operator must be able to see the surface of the water at a point 100 feet forward of the bow when the boat is underway and at a normal running angle.

What are normal running angles? Do boats actually meet the new ABYC standard? To answer

these questions, 270 boats were photographed while running at "normal" speeds. Boat sizes ran from small runabouts to large cruisers, operators were standing, sitting in the seats, on the seat back, and kneeling. All boats were photographed at random in profile as they passed the photographer at various speeds on a canal in Florida.

Slides were projected onto large pieces of paper and trim angles relative to the horizon, visibility angles, and several other parameters were drawn onto the paper. By establishing the length of each boat through manufacturers literature, etc., the proper scale was established and measurements could be made.

3.3.1.7 Results and Conclusions

Results are tabulated below:

	No. of Boats Measured	Av. Length (feet)	Visibility Distance Average (feet)	Visibility Distance Between Seated & Standing Oper.	Running Angle Average (degrees)	No. of Cases Where Visibility Was Obscured	# of Drivers Standing or Sitting on Seat Backs & Percentage of Total
Open Boats	12	13.4	22.4	N/A	3.75	3-25%	0-0%
Runabouts	107	17.9	96.3	141'	3.6	4-4%	38-36%
Bow Riders	58	19.2	76	83'	3.2	7-12%	21-36%
Center Console	12	17.0	51.1	N/A	4.7	5-42%	9-75%
Cruiser	76	30.9	137.4	174'	3.9	11-14%	20-33%
Houseboat	2	34	11.3	N/A	2.9	0-0	2-100%
TOTAL	270	20.8	96.5	N/A	3.6	27-10%	90-33%

The average length of the boats measured was only nine tenths of a foot from the average length of boats involved in collisions in CG-357.

It is interesting to note that the average visibility distance was within three feet of the ABYC recommended maximum for obscured visibility. This means that almost half of the operators in the boats that were photographed had an obscured visibility area greater than that recommended by ABYC; only half of the boats measured met the ABYC Standard. Runabouts and cruisers had the worst visibility problems and accounted for over two thirds of the boats measured. So the most prevelant boats have the greater visibility problems.

Visibility distances were plotted for standing and seated operators on the same boat when people were seated and standing close enough to the helm to get an accourate measurement. In the case of runabouts the operator could see the water an average of 141 feet closer to the boat when he either stood up or sat on the top of the seat backrest. In cruisers, the operators could see the water 174 feet closer when they were standing. These figures don't include the number of drivers that were standing because the horizon would have been completely obscured if they sat down. In fact one third of the boat drivers were either standing or sitting on the top of the seat back.

Most astonishing was the fact that a full 10 percent of the drivers of the boats photographed couldn't see the horizon forward of the boat because it was obscured by the bow, cabin top, objects, or people. Repeated, 10 percent of the drivers couldn't see where they were going.

Forward visibility problems were most prevelent in center console type boats with 42 percent of their drivers not being able to see the horizon forward. It is interesting to note that the running angle of the center console boats was highest at 4.7 degrees with 3.6 degrees as the overall average.

The photographic study reinforced the theory that there is a visibility problem with small pleasure boats. More research is needed to further define the problem and, hopefully, define solutions.

Is the 100 foot ABYC standard realistic? How far in front of the bow should one be able to see the water? Should that distance be related to speed, boat size or boat type? We know many collisions have happened because the operator didn't see the object that he hit. But maybe he couldn't see it. These problems span only the basics, that is, the ability to see the water in front of the boat and don't include the added visibility problems of glare, dark tinted windshields, windshield washers and wipers, or anything about the sailboat visibility problem.

3.3.2 Control Forces

3.3.2.1 Introduction

The amount of effort it takes to turn the steering wheel and manipulate the throttle and shift control lever(s) can effect operator performance, operator rate of fatigue, and can, if excessive, cause operator failure and possible collision.

The steering wheel is the most important control since it is manipulated almost constantly while driving a boat. It should have some minimum force required to turn the wheel, a range of forces required to manipulate the boat under "normal" conditions, and a maximum force limitation necessary to turn the wheel under infrequent high torque loads.

The shift/throttle levers are generally used less frequently than the wheel, therefore, control forces can be somewhat higher.

Boats are operated by members of both sexes. Therefore, the controls must be designed so that the weakest member of a given segment of the population can use them.

This chapter will deal with defining the boating population, defining their physical capabilities and relating those capabilities to existing hardware.

3.3.2.2 The Population

For design purposes most human factors engineers use 90 percent of the male and female populations in their calculations. A system requiring man/machine interface is, therefore, designed in such a way that the smallest or weakest five percent of the population and the largest or strongest five percent of the population is excluded. The remaining population is expressed as those people falling within the fifth through the ninety-fifth percentile. The systems are designed for the included population.

3.3.2.3 Physical Capabilities - Steering Wheel

3.3.2.3.1 Maximum Forces - Intermittant - Steering — At times, due to unusually high torque loads during rapid accelerations or while re-entering the water after jumping a wave or wake, an unusually high force may be required to either turn the wheel or maintain a heading. These forces should not surpass the capabilities of the weakest segment of the population for which the system is designed. Results of the National Boating survey (Ref. 5) show that approximately one quarter of boat operators are female. Therefore, unless we are sure that a particular boat won't be operated by women, the steering wheel forces should not exceed the capabilities of the 5th percentile female.

A study of Figure 3-11 (Ref. 6) shows the results of the forces exertable on a steering wheel by 33 Air Force men. The 15" diameter wheel was positioned in 16 different positions and was rotated left and right using the left hand only, right hand only and both hands. Push/pull data was obtained by Hemsicker (1955) from 55 University of Michigan men aged 17-25 at each of five elbow angles (Ref. 6). Although both studies were aimed at collecting data for Air Force purposes, the location and size of the wheel and the location and direction of movement of the push/pull apparatus closely approximates the position of the steering wheel and shift/throttle control on most boats. The data reflects the muscle strengths of physically fit young men as opposed to middle aged boat owners or their wives. Therefore, the numbers must be altered to correlate with the boating population.

Movement	Control Location From SRP Forward (in)	Control Position-Deg. of Turn Right or Left of Neutral	Right Hand			Left Hand	Both Hands	Both Hands
				Percentiles				
			Mean	5th	95th	Mean	5th	Mean
Rotate Right	23-1/4	90 Left	42	26	82	48	68.4	91
		0	60	35	98	39	65.6	101
		90 Right	40	22	68	35	45.5	71
	19	90 Left	46	27	94	48	74.1	101
		0	63	30	104	43	54.3	101
		90 Right	41	22	87	43	54.1	81
	15-3/4	90 Left	53	19	96	43	52.9	101
		0	59	27	97	39	55.8	101
		90 Right	46	20	91	43	54.2	91
	13-1/4	90 Left	52	21	98	43	67.2	111
		90 Right	51	19	111	48	55.8	101
	10-3/4	90 Left	59	27	101	35	55.8	101
		45 Left	69	24	121	48	68.4	132
		0	48	20	96	43	51.4	91
		45 Right	51	24	118	56	72.8	111
		90 Right	54	15	112	56	65.9	121
Rotate Left	23-1/4	90 Left	38	21	73	39	47	71
		0	39	20	86	55	65.1	92
		90 Right	55	26	109	44	61	102
	19	90 Left	43	22	76	39	52.3	82
		0	44	25	95	66	75.1	102
		90 Right	52	33	104	55	95.1	122
	15-3/4	90 Left	43	27	82	39	59.4	82
		0	46	27	112	61	75.1	102
		90 Right	50	29	86	61	82.3	112
	13-1/4	90 Left	44	26	86	44	76.5	102
		90 Right	45	25	99	66	93.7	122
	10-3/4	90 Left	47	23	91	55	68.1	102
		45 Left	54	21	123	50	55.3	102
		0	46	26	88	55	64	92
		45 Right	54	31	120	66	100.5	133
		90 Right	42	21	104	72	92.3	122

Movement	Elbow Angle (Degrees)	Mean	S.D.	Right Arm Percentiles		Range	Mean	S.D.	Left Arm Percentiles		Range
				5th	95th				5th	95th	
Up	60	49	18	20	82	8- 90	44	18	15	82	10- 95
	90	56	22	20	106	5-114	52	22	17	100	10-107
	120	60	24	24	124	10-142	54	25	17	102	10-128
	150	56	28	18	118	10-139	52	27	15	110	11-140
	180	43	22	14	88	9-101	41	23	9	83	4-105
Down	60	51	21	20	89	13- 96	46	18	18	76	12- 88
	90	53	20	26	88	16- 94	49	20	21	92	10-108
	120	58	23	26	98	22-110	51	23	21	102	15-134
	150	47	18	20	80	16- 94	41	16	18	74	12- 80
	180	41	18	17	82	13-116	35	15	13	72	40- 89
Pull	60	63	23	24	74	16-117	64	23	26	110	14-135
	90	88	30	37	135	18-163	80	28	32	122	12-156
	120	104	31	42	154	26-163	94	34	34	152	20-177
	150	122	36	56	189	28-222	112	37	42	168	25-187
	180	120	37	52	171	26-185	116	37	50	172	31-182
Push	60	92	38	34	150	24-174	79	31	22	164	22-180
	90	86	33	36	154	25-178	83	35	22	172	21-190
	120	102	43	36	172	30-220	99	42	26	180	25-203
	150	123	45	42	194	34-210	111	48	30	192	19-211
	180	138	49	50	210	33-215	126	47	42	196	26-215

(All measurements, except those otherwise indicated, are expressed in pounds.)

Figure 3-11. Human Strength Characteristics

Human strength increases rapidly in the teens, more slowly in the early 20's, reaches its maximum by the middle to late 20's, remains at this level for 5 to 10 years, and thereafter declines slowly, but continuously (Ref. 6).

From the various studies relating strength to age summarized by Fisher and Birren (1946) (Ref. 6), the following estimates may be made: By the age of 40 muscle strength is approximately 90 to 95 percent of the maximum in the late 20's. By age 50 it is about 85 percent, and by 60 about 80 percent of its maximum. Miller (1959) found muscle strength at 65 to be about 75 percent of that exerted in youth (Ref. 6).

Women comprise 25 percent of the boat operator population according to the National Boating Survey, Figure 3-12. Damon (Reference 6) says that women are in general about two thirds as strong as men, the amount varying for different muscle groups. In the forearm flexors women have only about 55 percent of men's strength; therefore, the data in Figure 3-11 should be reduced by 45 percent to reflect the maximum force exertable for the fifth percentile woman operator.

If we design for 90 percent of the population, we would eliminate approximately five percent of the youngest group and five percent of the oldest portion and design for the population remaining, or those people between the ages of 14 and 60.

The above statistics are presented to demonstrate that the rather high numbers must be reduced quite a bit to fit the boating population. In fact, it is probable that the strength figures presented in Figure 3-11 will have to be reduced by approximately 70 percent to accommodate the fifth percentile female operator.

Age (Years)	Male	Female	Total	Percent
Under 12	436,124	141,003	577,127	3.6
12-15	609,705	319,194	928,899	5.6
16-19	1,311,872	708,311	2,020,183	12.4
20-25	1,730,060	633,296	2,363,356	14.4
26-30	1,554,923	480,521	2,035,444	12.4
31-40	2,170,372	762,409	2,932,781	17.9
41-50	2,116,470	609,836	2,726,306	16.7
51-60	1,372,263	276,446	1,648,709	10.1
Over 60	985,942	151,755	1,137,697	6.9
Total	12,287,731	4,082,771	16,370,502	100.0

Figure 3-12. Boating Population

In order to get a feel for the problem area, Wyle Laboratories measured the maximum steering loads on 7 boats. In two of the 7 cases, maximum loads were well above 20 lbs. See Figure 3-13. There is a possibility that the fifth percentile woman would not be able to turn the wheel in those two cases.

Since it appears that there may be a problem with a portion of the boat operator population not being able to turn the wheel due to excessive wheel loading, further research is needed to:

1. Accurately define the boat operator population and determine what portion of that population should be excluded from design standards, if any.
2. Determine the physical strength characteristics of the weakest portion of the included population.
3. Measure the steering wheel loads on a representative sample of boats.
4. Compare strength characteristics with load measurements.
5. Define the problem, if any.
6. Research the reason for the problem.
7. Recommend solutions.

3.3.2.3.2 Sustained Forces - Steering Wheel — The maximum intermittant forces defined above must be regarded strictly as intermittant or occasional. Many studies have showed that the exertion of force against an object quickly produces fatigue and fatigue greatly reduces strength. For example, after maximum force had been exerted on a control stick or foot pedal for five minutes, strength was reduced to about one third of its maximum value - even after a five minute rest period (Hertel, 1930) (Ref. 6). Additionally, Ikai and Steinhaus (1961) (Ref. 6) found that with a maximum pull (forearm flexation) once a minute for 30 minutes, there was an irregular, but gradual, downward trend in strength amounting to 10 percent at the end of the period.

Caldwell (1963) performed a strength endurance study using 36 college students, 18 male and 18 female (Ref. 6). The numbers have only a general application since the subjects were in the modified prone position and were asked to exert a pulling force on a handle in front of

their shoulders. However, its relevance seems to be in the steep slope of the degredation of maximum force as a function of time. In general, only about 15 percent of maximum strength can be exerted over long periods throughout the day without muscle fatigue.

Based on that data maximum forces shown in Figure 3-11 must be reduced by about 85 percent to represent the maximum sustained forces that should be found on pleasure boat steering wheels. Sustained forces would then be down in the 5 to 10 lb area.

In order to get a feel for the problem, the sustained steering wheel loads were measured on the 7 boats referenced in 3.3.2.3.1, above, while the boats were underway. A torque wrench was modified in such a way that the displacement of the pointer on the scale produced an input into a potentiometer. The output of the potentiometer was recorded and later analyzed to determine the precise steering wheel loads.

While the boat was moving straight ahead at a predetermined rpm, the apparatus was attached to the center steering wheel nut in such a way that the torque wrench was either vertical or pointing forward, depending on the steering wheel angle. The driver was asked to turn the boat using the torque wrench to the left and then to the right. He was to perform the task twice. The first time he was to turn the wrench slowly through a 90 degree arc to port, then back to straight ahead, then slowly through a 90 degree arc to starboard and slowly back to straight ahead. The second portion of the test was identical except that the driver was asked to move the torque wrench as fast as he could to simulate a "panic" turn.

Figure 3-13 shows the results of the study. The average amount of force required to turn a steering wheel was 12 lbs. Since the average is more than the probable maximum should be (5 to 10 lbs), there definitely seems to be a problem. The VAST study showed that fatigue caused a degredation in operator performance. It appears as if steering wheel loads are at a high enough level that they could cause the operator to become fatigued.

More research is needed in this area and should be of a similar nature as the research specified in 3.3.2.3.1, above.

Boat	Idle		Cruise		Full Throttle		Average		Maximum
	Port	Starboard	Port	Starboard	Port	Starboard	Port	Starboard	
19' I/O									
Fast Turn	8.3	10	9.3	14	6.7	18	8.1	14	18
17' Outboard									
Fast Turn	8	12	13.3	5.3	13.3	6.7	11.5	8	13.3
23' I/O									
Slow Turn	4.7	6	0	17.3	3.3	20	2.6	14.4	20
Fast Turn	No Data	No Data	5.3	More Than 20	5.3	More Than 20	5.3	More Than 20	More Than 20
25' Inboard									
Slow Turn	1.6	1.6	2.1	4	2.7	4.7	2.1	3.4	4.7
Fast Turn	4	4.8	4	8.6	4.7	8.7	4.2	7.4	8.7
22' Inboard									
Fast Turn	6	8.4	6	7.6	4	14	5.3	10	14
25' Inboard									
Fast Turn	2.4	2.9	6.7	5.3	No Data	No Data	4.6	4.1	6.7
27' Inboard									
Slow Turn	4.7	6.4	8	14.4	9.3	17.3	7.5	12.7	17.3
Fast Turn	6.7	10.7	9.3	16.7	9.3	23.3	8.4	16.9	23.3

Figure 3-13. Steering Wheel Loads (lbs)
(Tangental Rim Loading)

<u>3.3.2.3.3 Minimum Forces - Steering Wheel</u> — The wheel should have some minimum turning resistance or "feel". According to Wesley Woodson, a pioneer in the area of human factors, tests have shown that cars with very low steering wheel forces tended to wander within the driving lane and were subjectively evaluated as more difficult to steer.

On unpublished study performed by a major boat company recommended two pounds as the minimum force required to turn the wheel at the rim. A survey of several cars with power steering showed that the force required to turn the sheel one-half turn on either side of straight ahead was between one and three pounds.

System friction actually dictates that there will be some amount of resistance. The wheel forces on several boat steering systems were measured and were found to be between one and three and one-half pounds with most falling in the two pound plus or minus one-half pound catagory.

Research is needed to determine if a minimum steering wheel force is needed or justified for boats. If so, criteria should be established and compared to actual measured values. Realistic minimum resistances could then be recommended.

<u>3.3.2.3.4 Balance - Steering Wheel</u> — Unlike automotive steering, the small boat steering system is generally not balanced in that the operator usually has to overcome a force on the wheel in one direction. If he were to take his hands off the wheel, it would turn in one direction until it came to its mechanical stop and the boat would be driven in circles. Most outboard motors and stern drive units have adjustable rim tabs which help to "neutralize" the helm, but they are only effective for one speed range and one load condition.

The result is that the operator must constantly apply a turning force on the wheel to maintain a constant heading. That force must be overcome and additional force must be applied to turn the boat away from the direction that it wants to turn.

That turning force should not be greater than the maximum sustained force that can be applied by the fifth percentile operator of the population expected to operate the boat.

In addition, high acceleration rates on outboards and stern drives tend to produce a rotating force on their lower units which is transmitted directly to the wheel in many steering systems.

Because the steering wheel forces obtained during high accelerations are intermittant and are controllable by the operator (she doesn't have to pop the throttles from idle to wide open), they should not exceed the maximum intermittant force as described in 3.3.2.3.1.

3.3.2.3.5 Feedback — Experienced boat operators have their preferences for steering systems with feedback and those that don't provide a "feel" of the rudder. Some say that they want to "feel" the forces on the rudder so they can detect abnormal conditions before major problems occur. Others claim that since the steering is always out of balance anyhow they don't want to always have to apply pressure on the wheel to keep the boat headed straight.

Both seem to have a point considering safety, but more research is necessary before Wyle can take a stand one way or the other.

3.3.2.4 Physical Capabilities - Shift/Throttle Levers

3.3.2.4.1 Introduction — Unlike steering wheels which are relatively standardized, there are many different types of shift and throttle mechanisms that work and appear to be quite different. These differences will be discussed briefly.

Maximum (intermittant), sustained, and minimum forces will be discussed and will be compared to the forces measured on actual hardware.

3.3.2.4.2 Available Hardware — Unfortunately shift and throttle hardware has not been standardized within the boating industry.

Most outboard and many stern drive manufacturers are using the "single lever" shift and throttle mechanism wherein a single lever is used to actuate both functions. Pushing the lever forward or aft from a mid-position first actuates the shift mechanism then advances the throttle.

Because one control lever actuation actually moves two cables and their associated mechanisms, greater control forces can be anticipated than if each control lever moved only one cable.

Most inboard boats have separate throttles and shift levers for each function on each engine. Hence, a typical twin engined boat will have an array of four levers for speed and direction control.

A glance of the various manufacturers literature will show that these mechanisms come in all sizes, colors, and shapes. Except for the fact that a forward motion on the throttle lever increases rpm's and the forward position of the shift lever puts the gearbox in forward gear, there seems to be no standardization.

Industry groups such as ABYC have published standards recommending lever position standardizing and color coding of hand grips, but a glance at the boats in existance will show that these standards are not being met.

Lack of standardization can cause human error. The SAE Construction and Industrial Equipment Design Committee found in 1967 that many equipment related accidents were happening because operators were activating the wrong levers. It was found that the same function in different pieces of hardware was controlled by different levers; therefore, operators used to one forklift, for instance, would make significantly more control errors after changing to a different make or model forklift.

Similar studies and results have led to standardized control locations in airplanes, helicopters, automobiles and most military vehicles.

There is reason to believe that standardized control lever configurations would reduce human error and, hence, reduce accidents. Studies should be conducted to determine what effect non-standardized controls have had on the boating accident rate and what effect a standardized control standard might have on that accident rate.

3.3.2.5.3 Maximum Forces - Levers — Figure 3-11 shows the push/pull capabilities of 55 college men. Using the boating population defined in the National Boating Survey Ref. 5, (see 3.3.2.3.1), the data should be modified to represent the boat operator population.

Since many control levers operate over an arc of approximately 180 degrees and many are located forward of the operator, the levers must be pulled up or pushed down at their extreme positions and pushed and pulled in the middle range. Therefore, the motion that the human is weakest in (push, pull, up, down) must be used as the limiting number. From Figure 3-11, we find that humans are weakest in the down movement closely followed by the up movement. Therefore, the maximum allowable force required to move a control handle should be derived from the humans strength capability to push a lever down.

Figure 3-11 also shows that the mean strength of the 5th percentile college student in the down movement is about 22 lbs. When that number is reduced to account for sex and age, it should become just under 10 lbs.

The maximum forces described above are not only applicable to continuous lever forces once the control is in motion, but also to the breakout forces or those forces necessary to initiate movement of the control.

The throttle system should be designed to minimize breakout forces. The force required to move the handle should be as constant as possible throughout the range.

However, there should be positive detents in the shift lever while moving the handle into and out of neutral.

A single lever control should have another detent or marked "feel" when moving the handle past the in gear - idle position into the range where a handle movement will increase the throttle. This detent should be somewhat less than the neutral detent to avoid "overshoot."

The problem becomes that of defining the amount of breakout force as a function of the continuous forces on the lever.

The human engineering literature should be searched and experiments run if necessary to determine the breakout force/continuous force ratio.

Collision reports should also be searched to determine throttle overshoot or if excessive control forces contributed to a significant number of accidents.

But first, in order to determine if a potential problem exists, the forces required to move the shift and throttle handles of five boats were measured. Continuous forces and also breakout forces were determined using a single spring scale. Results as shown in Figure 3-14 below.

	FORCES (LBS)	
	Breakout Max.	Continuous
17' I/O with Single Lever Control	5	4
24' OB Pontoon Boat	15	8-10
27' I/O Twin Engine W/Single Levers		
Forward	25	5-8
Reverse	35	5-10
17' O/B Center Console	18	8-10
16' O/B	18	5-15
Average	19.3	7.6

Figure 3-14. Shift and Throttle Lever Forces

From these preliminary results, it appears that a problem may be present. The average breakout force of the levers measured (19.3 lbs) is almost twice the probable maximum force that can be exacted (10 lbs) on the control by the weakest segment of the population. In addition, the average continuous force measured (7.6 lbs) was close to the maximum force proposed.

Research is needed in this area also. Maximum forces permissable for the pleasure boat population should be accurately defined and a larger sample of control forces should be measured.

If a problem indeed exists, researchers should work with control and engine manufacturers to determine the most cost-effective solution.

3.3.3 Noise Levels

3.3.3.1 Introduction

Miller (Reference 2 , Chapter III) presented the potential noise problem within the pleasure boat area with a good amount of expertise. For the purposes of introducing the problem area and presenting some background to the Wyle research effort, portions of Miller's chapter will be paraphrased below.

> "In light of (the available data), namely the present in-boat noise levels can exceed 80 dBA, a three-fold safety problem may be prevalent during small boat operations due to noise. First, effective speech communication may be impaired thereby reducing the possibility that the operator could be forewarned of impending danger by another occupant of the craft. Secondly, noise-induced temporary threshold shifts (TTS) may be apparent among a significantly large portion of boat operators, thereby reducing the likelihood that these operators could detect auditory warning signals from any source, even with the motor off. Thirdly, noise-induced sensorimotor, perceptual-motor, or other performance decrements may result from exposure to noise from currently designed boat engines.
>
> Speech communication begins to be impaired at noise levels above approximately 65 dBA. At 85 dBA it becomes necessary to shout to a person only two or three feet away in order to be understood by him. Since these levels of noise probably exist on all presently manufactured boats, one can surmise that speech communication is at least partially impaired with the attendent possibility that verbal warnings of impending danger, made by a passenger, would not be heard by an operator."

Other studies (Reference 9) have shown that reliable speech communication at a three foot speaker-to-listener distance is effectively masked when the background noise level rises above 73 dBA.

> "(Miller, Reference 2) Noise induced TTS is apparent at noise levels in the 60 to 80 dBA range depending on duration of exposure. Again, assuming an operator has sustained a TTS, one can speculate that this decrement in hearing ability could be a causal factor in those accidents in which a pre-accident warning signal was not heeded.
>
> Even though it is not always possible to definitively delineate dose-response relationships between noise and non-auditory physical or psychological disorders, disturbances of this type have nonetheless been documented. One could speculate, however, that should such disturbances be present in boat operators, as a result of boat generated noise, significant psychophysiological performance decrements could result with an attendent potential safety hazard. ....

Speech Communication Interference

The sound energy of speech is distributed over the frequency range from below 100 to above 10,000 Hz. .... The bulk of information contained in speech is contained in the 200 to 6,000 Hz range, however, in consideration of these facts, a number of sound measuring techniques and weighing schemes have been formulated to indicate the degree to which speech is masked by various noises. Among these are the widely recognized A-weighted scale, (dBA), the Preferred Octave Speech Interference Level, (PSIL), and the Articulation Index, (AI). ....

Based on the data of Magrab (1973) ... it can be seen that a significant speech interference problem can exist on some presently designed powered boats. For example, at 90 dba (83 PSIL), an operator located approximately 13 feet from any other occupant who might be attempting to verbally warn the operator of immediate impending danger, could not be heard by the operator. The possibility that such a situation could exist, and the ramifications thereof, are a matter for potential concern.

Noise Induced Temporary and Permanent Threshold Shifts
(TTS and NIPTS respectively)

Compounding the speech interference problem is the fact that the operator may have sustained a TTS as a result of boat engine noise, thereby reducing further his chances of detecting verbal or other auditory warning signals. This fact, coupled with the operator's age and occupational noise experience may still further compound the problem if the operator has sustained a NIPTS. ....

In the total systems context, high noise levels in boats could be considered to be one more contributor to the possibility that boat operators will sustain NIPTS. From a narrower viewpoint, however, pleasure boat noise could not be considered as a prime contributor to operator NIPTS since exposure periods are widely intermittent and generally of short duration. Of more immediate interest, therefore, is the probability that the operator will sustain TTS. The audiometric characteristics of TTS are almost identical to NIPTS .... but the threshold shift is temporary, eventually returning to pre-exposure levels.

Kryter (1970) in a compilation of work done by Ward, et al. (1959), Kryter (1963) and Kylin (1959), ... (showed) that TTS can occur after only 15 minutes of exposure to high noise levels. He also points out, among other things, that: 1) the greatest amount of threshold shift from a given noise band occurs within one octave above the frequency of the noise band for both TTS and NIPTS, and 2) the frequency regions most susceptible to TTS are likewise most susceptible to NIPTS.

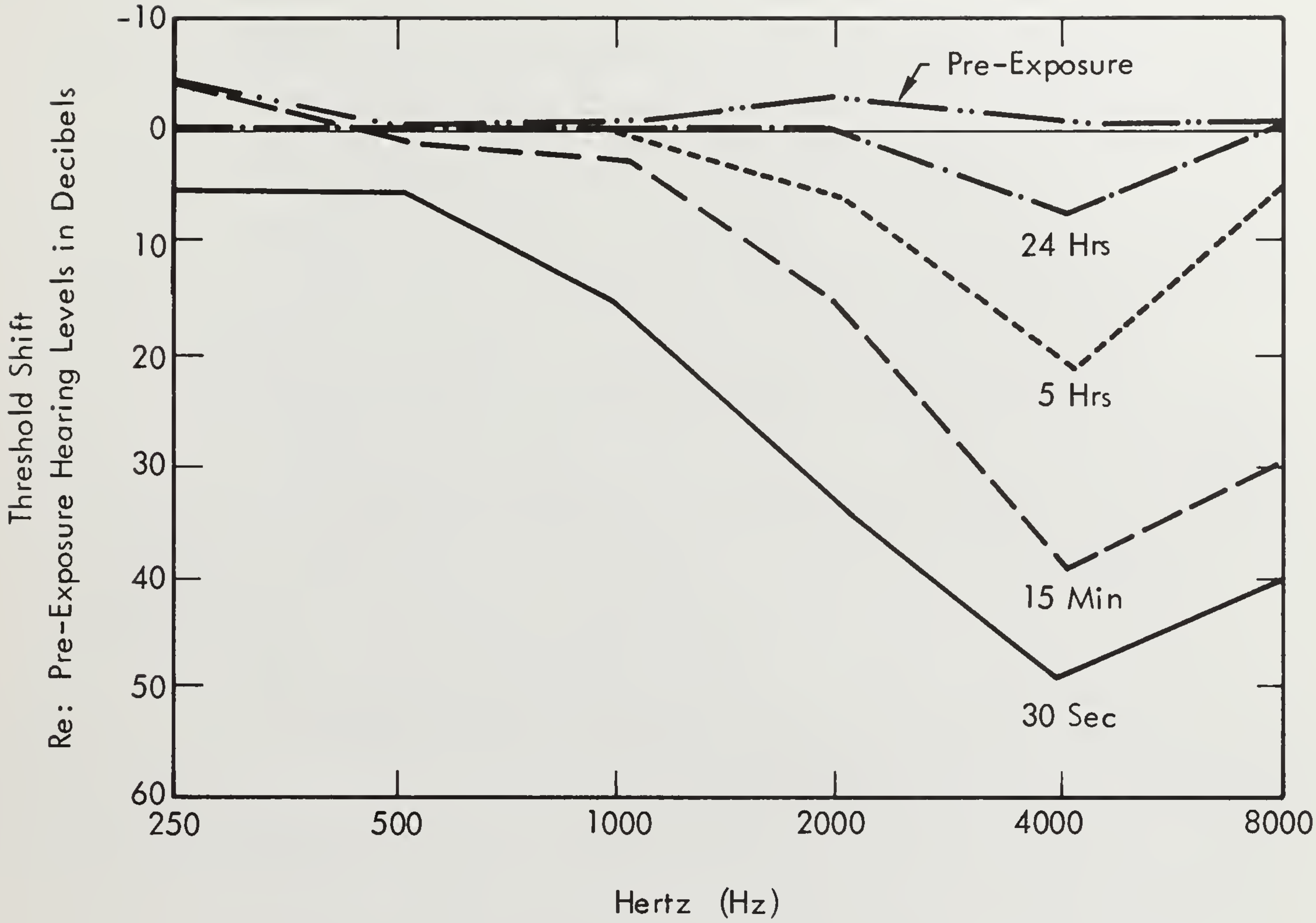


Figure 3-15. Hearing Levels Measured at Various Times After a Two-Hour Exposure to a Broad-Band Noise at 103 dBA as Compared With Pre-Exposure Determinations (Single subject data taken from the Public Health Service Laboratory in Cincinnati, Ohio)

Recovery times from TTS are dependent on the level of noise present during exposure and the time duration of exposure. Figure 3-15 is an example of recovery times from relatively high noise levels.

Since the possibility that at least temporary hearing loss can occur at sound pressure levels in the 60 to 80 dBA range, it could be easily assumed that a yet undefined degree of TTS is present in a significantly large portion of small power boat operators during normal operations. ....

Psychological and Other Physiological Effects

Besides hearing loss, noise is known to be capable of initiating a number of other physiological reactions known as somatic responses. Davis et al. (1955) have hypothesized that these reactions are possibly related to feelings and emotion, bodily health, and to the ability of the person to perform mental, perceptual, or motor tasks. It should be noted however, that these responses are widely varied throughout the body and among individuals, are greater for intense than for weak sound, and cease or adapt out with continued stimulation. ....

The short term effects of these somatic responses on the physiological or psychological well being of an individual are inconclusive .... It remains to be seen, however, whether or not a long term physiological "debt" effect is created by such responses. In this context, boat generated noise could be a contributing factor, should such an effect become evident. ....

Perceptual narrowing or reduction in visual field of view is reported by Benko (1962) and Hockey (1969). Hockey reports the presence of 100 db noise resulted in an increased number of missed signals on a secondary peripheral vision task that accompanied a primary tracking task. Performance on the tracking task increased with time under these conditions. Exposure to BaseLine, 70 db "quiet" noise resulted in the opposite effect, in that performance was lower on the primary task and higher on the secondary, peripheral vision task. These experimental results seem to indicate a funneling of attention during noise exposure at the expense of peripheral awareness. This effect could be deleterious in situations where a wide peripheral field is necessary, such as is required by the boat piloting task requirement that a continual peripheral "search" be made for objects in the water or oncoming vessels.

The effects of noise on mental, perceptual motor, and other non-auditory tasks have recently been reviewed by Kryter (1970) and NIOSH (1972), among others. The results of experimental work done in this area is confounded by problems of poor specification of the noise stimulus, sample group sizes that are too small to make "whole world" generalizations,

test scoring discrepancies, and in some cases, ill-planned experimental designs. Generally speaking, however, the following points can be made about task performance in a noise environment:

1. Intermittent high SPL noises are more likely to disrupt work performance than are continuous noises of a comparable level.

2. As discussed earlier, presence of high noise levels tends to divert attention from peripheral tasks to the more central task. Central task efficiency remains relatively constant, and may even improve, at the expense of peripheral awareness.

3. Tasks requiring a high degree of mental effort and attention are vulnerable to the distracting characteristics of high noise levels.

4. Quality rather than quanity of work is generally affected by high noise level environments.

5. Individual attitudes and personality traits can tend to overcome degrading noise effects. Poorly motivated, "anxious," "nervous" people are more likely to be adversely affected by high noise environments than are motivated, "calm" people.

Due to the inconsistencies in the data on this area of noise effects, it is difficult to state with certainty that noise-induced psychomotor or sensorimotor performance decrements occur in the boating environment. However, the possibility that "tunnel vision" could result during long cruises at relatively high noise levels could be a cause for concern. ...."

In summary, Miller referenced one study wherein noise levels on board several small outboard powered boats, several inboard powered boats, and two Coast Guard Cutters were measured. His conclusions were that:

1) boat noise masks reliable speech communication.

2) boat noise may induce temporary hearing losses.

3) boat noise may contribute to permanent hearing losses.

4) boat noise may contribute to certain physiological reactions such as reduced peripheral vision.

Not discussed in the Miller report, however, is the "hot rod" problem. Since fast vehicles, whether they travel on land, air, or water, are traditionally noisy, people who want their

boats to appear fast tend to want them to be loud. Hence, the "hot rod" boats generally are sold without mufflers. How loud are they? Could the fact that they are noisier than other boats contribute to their being in or causing collisions? Or is their main fault only the possible annoyance to other people in the immediate area?

3.3.3.2 Additional Data

Miller did quite a credible job of presenting the boat noise problem area. However, his data bank consisted of only one study (Reference 2). As part of Task III, Wyle analyzed data on other noise studies including studies that measured only water-induced boat noise and a study that measured air noise inside the human ear at various wind speeds. Wyle also measured the noise level of a group of boats that weren't represented in the available data base including cabin cruisers and "hot rod" boats.

<u>3.3.3.2.1 Sound Levels - Boats</u> — A major outboard motor manufacturing company measured the sound levels of their 1972, 1973 and 1974 motors on three different boats. Results of their study are presented in Figure 3-16 below.

BOAT	HP	RPM	SOUND LEVEL AT OPERATOR'S EAR		COMMENTS
			1974 Eng.	1973/2 Eng.	
14' Aluminum	2	4200	86.5	92.0	Measured 3' from Eng.
14' Aluminum	4	4700	85.0	86.5	Measured 3' from Eng.
14' Aluminum	6	4200	85.0	84.5	Measured 3' from Eng.
14' Aluminum	9.9	5100	86.5	93.0	Measured 3' from Eng.
14' Aluminum	15	6000	94.0	93.0	Measured 3' from Eng.
15' Fiberglass	25	5400	83.5	87.5	Measured 7' from Eng.
15' Fiberglass	40	4600	90.5	92.0	Measured 7' from Eng.
15' Fiberglass	50	5600	90.0	89.0	Measured 7' from Eng.
17' Fiberglass	70	5100	88.5	86.0	Measured 8' from Eng.
17' Fiberglass	85	5000	93.0	94.0	Measured 8' from Eng.
17' Fiberglass	115	5000	92.0	93.0	Measured 8' from Eng.
17' Fiberglass	135	5000	93.0	98.0	Measured 8' from Eng.
17' Fiberglass	70	5100	88.5	86.0	Measured 3' from Eng.
17' Fiberglass	85	5000	93.0	94.0	Measured 3' from Eng.
17' Fiberglass	115	5000	92.0	93.0	Measured 3' from Eng.
17' Fiberglass	135	5000	93.0	98.0	Measured 3' from Eng.

Figure 3-16. Outboard Sound Levels (dBA)

In 1973, Wyle Laboratories conducted a cost-effectiveness study for noise reduction of motorboats for the EPA in which the sound levels of many pleasure boats were measured. (Ref. 13) Unfortunately most sound measurements were made from a 50' distance per SAE J-34 and, therefore, are not applicable. Some sound measurements, however, were made on the after cockpits of inboard motorboats and are shown in Figure 3-17.

Measurements of 105 dBA for gasoline engines and 110 dBA for diesel engines were measured at the after cockpits according to the text, however, these extreme measurements did not appear in Figure 3-17.

Magrab (Ref. 14) studied sound levels of pleasure boats for the purpose of establishing noise criteria. The abstract of his report appears below.

"The noise emitted by recreational boats presents the following problems: (1) noise pollustion to by-standers, (2) communication difficulties on-board, and (3) permanent damage to an individuals hearing. A noise criteria must be determined first in order to solve these problems.

A noise analysis of various common recreational boats and engines was conducted from measurements taken in the field.

Standard test procedures for taking sound measurements exterior to and on-board recreational boats were established. The mean value of noise from large, small, and all motors were found to be 85.4, 80.2, and 82.9 dBA respectively.

A noise level of 65 dBA is considered moderately noisy by most people. Therefore, most all motors emit an unacceptable level of noise to people in boating areas such as lakes, rivers, etc. The problem of communication among individuals on-board recreational boats may present a safety hazard and fog situation where warnings of danger must be spoken or ships' whistles and fog signals must be heard. A high noise level such as 82.9 dBA over a long period of exposure may also be damaging to an individuals hearing. Standard test procedures have been established to measure the noise level emitted from recreational boats as a first step to help eliminate the above problems."

Sound level data from the Magrab report is graphically shown in Figure 3-18.

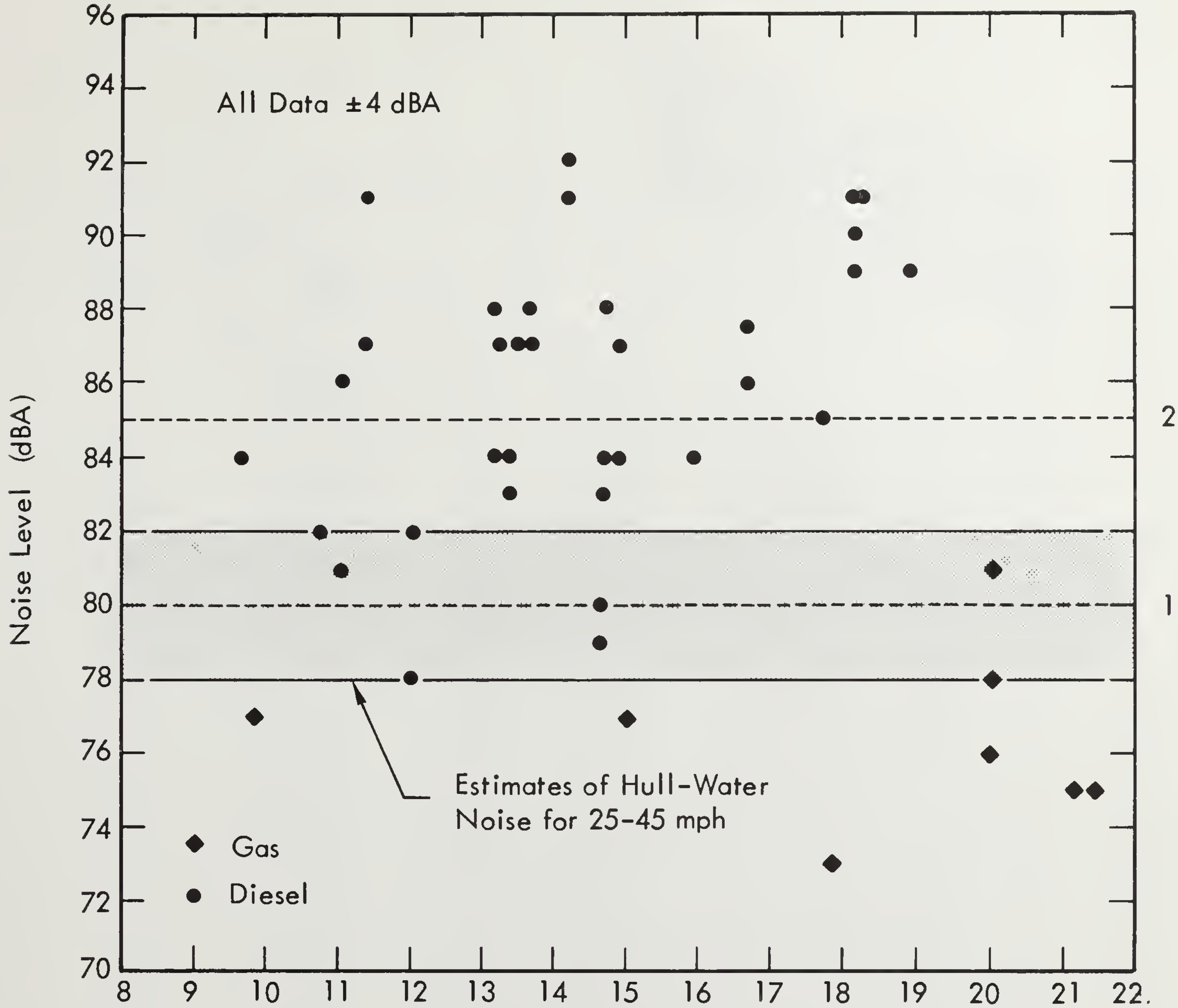
Wyle Laboratories recently measured the sound levels from the operator's position of eleven (11) boats. Results are shown in Figures 3-19 and 3-20. Sound levels were measured at idle or 1000 rpm, at a comfortable cruising speed, and at full throttle. When averaged they appear as shown below:

CONDITION	SPEED (MPH)	SOUND LEVEL (dBA)
Idle	6.2	69.1
Cruise	25.4	82.2
Full Throttle	35.6	90.6

If we consider 73 dBA background noise to be the upper limit for reliable speech communication while shouting (Ref. 9), then reliable speech communication is impossible when running at cruising speed or faster.

Two of the boats measured could be considered in the "hot rod" class. They were both 27' deep-V boats powered by twin inboards operating through sterndrives. Both had no mufflers and, in fact, had exhaust pipes less than one foot long. Their statistics appear below.

BOAT	HP	RPM	SPEED (MPH)	SOUND LEVEL (dBA)
1	600	1000	7	78
		3000	36	87
		4800	56	99
2	470	1000	6	77
		3000	28	86
		4200	42	92

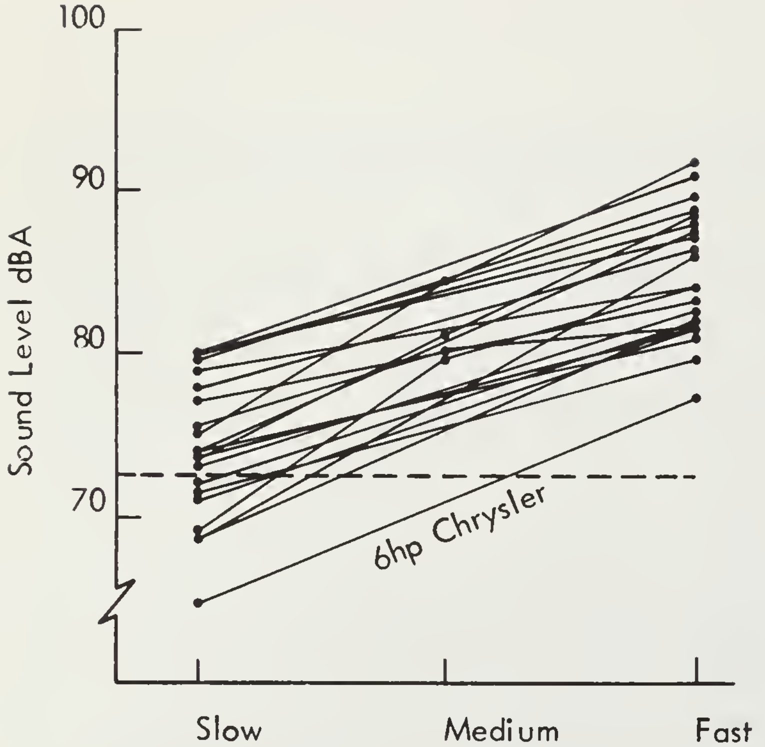


$$\frac{\text{LOA}}{\text{Maximum Total Power}} \quad \frac{\text{FT}}{\text{HP}}$$

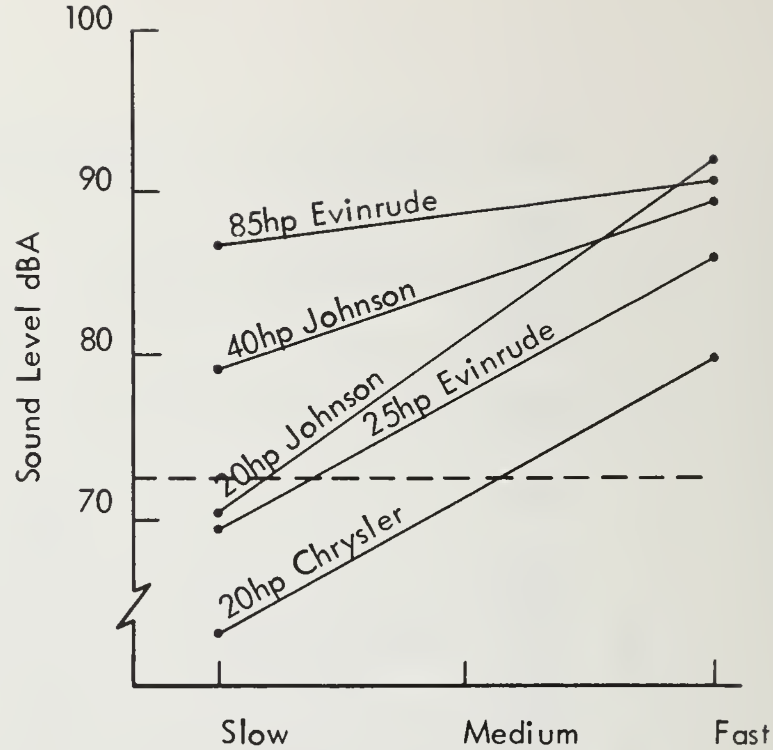
[1]Noise level at which speech communication is barely possible when shouting over a 2-foot distance.

[2]NIOSH ultimate goal limit for 8-hour daily occupational exposure to continuous noise for avoidance of significant hearing damage.

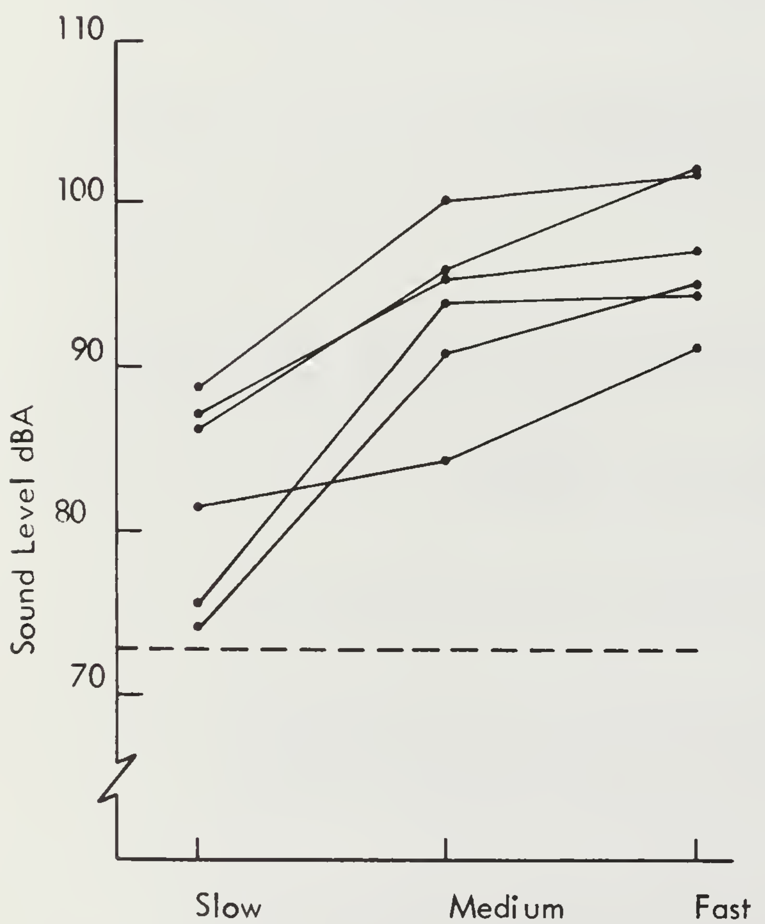
Figure 3-17. Inboard Motorboat After-Cockpit Sound Levels Measured Under Way at Maximum Engine rpm



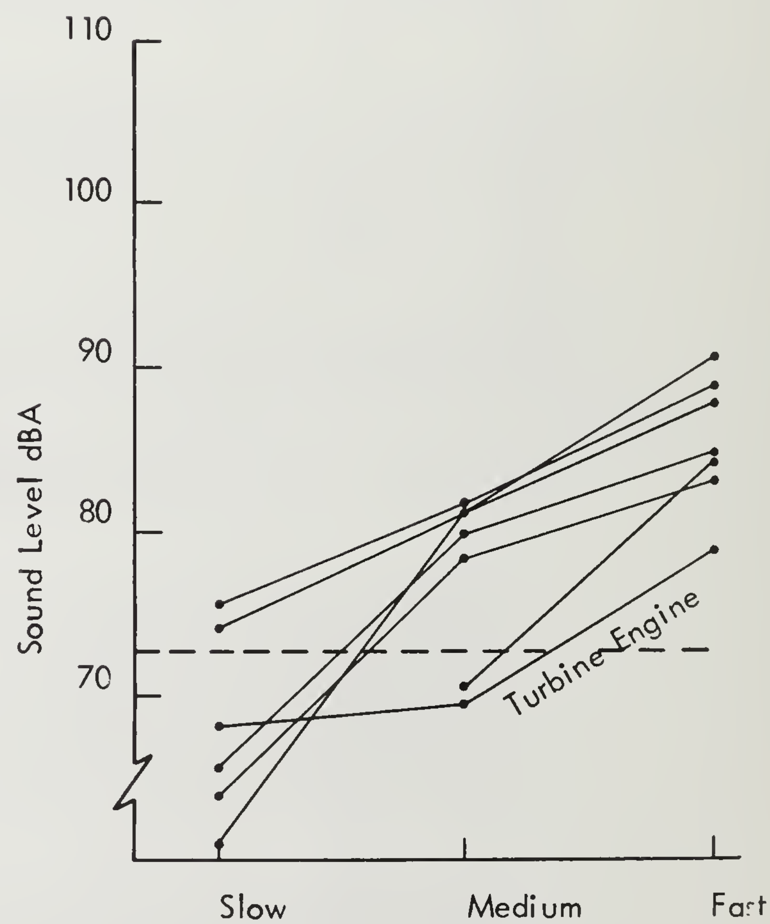
Outboard Engine Speeds - 2 hp, 4 hp, and 6 hp Engines Mounted on Small Boats



Outboard Engine Speeds



Engine Speeds - Sound Levels on 30' and 44' Coast Guard Cutters Measured at Operator's Position



Inboard Engine Speeds - 25', 32', 38', 44' and 48' Boats Measured at Operator's Station

Figure 3-18. Sound Level Measurements

BOAT LENGTH (Ft)	POWER TYPE	HP	RPM	SPEED (MPH)	SOUND LEVEL (dBA)
17	Outboard	135	4000	26	82
17	Outboard	135	5500	37	90
16	Sterndrive	130	1000	5	60
16	Sterndrive	130	2800	22	80
16	Sterndrive	130	3500	32	90
19	Sterndrive	200	1000	6	65
19	Sterndrive	200	2800	28	85
19	Sterndrive	200	3500	33	88
22	Inboard	200	1000	6	67
22	Inboard	200	2800	21	84
22	Inboard	200	4300	30	93
23	Inboard	235	1000	6	72
23	Inboard	235	3500	33	82
23	Inboard	235	WOT*	40	90
25	Inboard	260	1000	7	64
25	Inboard	260	2800	22	78
25	Inboard	260	4000	31	90
25	Inboard	200	1000	6	69
25	Inboard	200	2800	20	78
25	Inboard	200	3800	30	88
27	Inboard	600	1000	7	78
27	Inboard	600	3000	36	87
27	Inboard	600	4800	56	99
27	Inboard	470	1000	6	77
27	Inboard	470	3000	28	86
27	Inboard	470	4200	42	92
36	Inboard	660	1000	6	70
36	Inboard	660	2800	18	80
36	Inboard	660	4200	25	86
45	Inboard	850	500	6	75
45	Inboard	850	1500	18	84
45	Inboard	850	2250	25	90

* Wide open throttle

Figure 3-19. Sound Levels Measured on 11 Boats

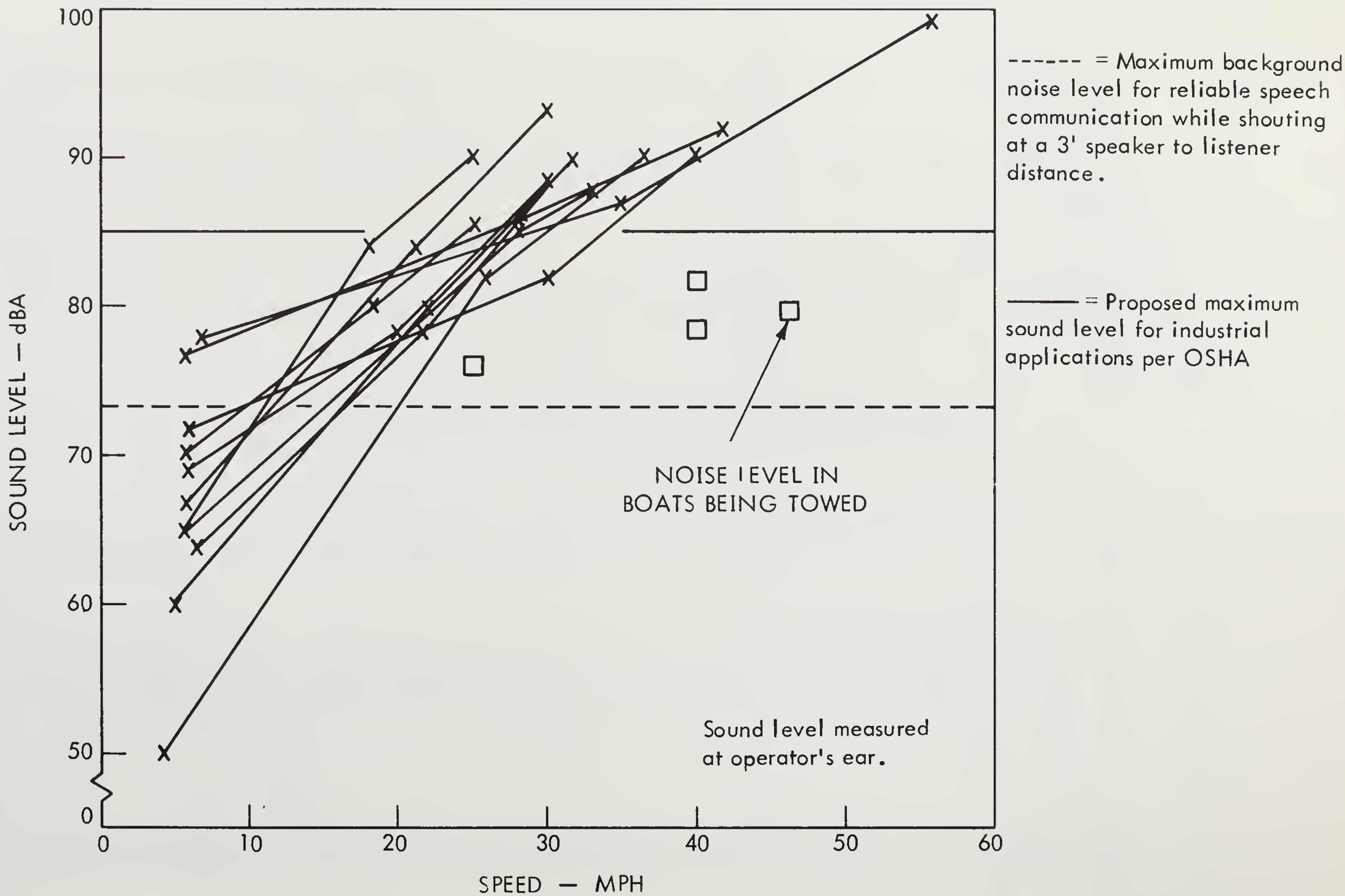


Figure 3-20. Sound Level Measurement on 11 Boats

Morgan (Ref. 9) states that reliable speech communication while shouting is impossible at a three foot distance when the background noise level is over 73 dBA.

As can be seen from the above sound levels, effective communication is impossible from three feet away at all speeds. And, according to Miller, temporary threshold shifts could occur at all speeds, even idle.

3.3.3.2.2 Water Noise — In 1973 the SAE Sound Level Committee measured the sound level of various boats under various configurations. A portion of their tests included measuring the sound level of four boats being towed through the water at their maximum speeds. Each boat was equipped with an outboard motor. The propellers were removed and the gearcase was faired. Sound levels were measured at the operator's ear position on each of the boats. Boat specifications and sound levels appear below and are shown in Figure 3-20.

BOAT NO.	LENGTH (FT)	HULL MATERIAL	HULL SHAPE	OUTBOARD (HP)	SPEED (MPH)	SOUND LEVEL (dBA)
1	14	Aluminum	?	25	25	78.0
2	15	Fiberglass	Cathedral	65	40	81.5
3	15	Fiberglass	V	65	40	78.5
4	17	Fiberglass	Cathedral	135	46.2	79.5
					37.8	79.4

Although the boat sample was small, it appears as if the water/hull interaction on boats with complicated hull bottom shapes creates slightly more noise than does the less complicated hull shapes. However, it remains unknown if the higher noise level was due to the hull shape itself, or the fact that there may have been more wetted surface on the cathedral hulls.

If the results were averaged, one could conclude that the sound level created by the water noise alone at the operator's station on a boat travelling at 39 mph would be over 79 dBA, or enough to mask reliable speech communication and cause temporary threshold shifts.

3.3.3.2.3 Wind Noise — Professor A. R. Howell of the University of Windsor conducted a study in 1973 for Outboard Marine Corporation (Reference 15) wherein he measured the sound level within the ear of ten subjects. The sound was produced solely by the wind as the subjects rode on top of a coasting truck moving at speeds from 20 to 70 MPH.

As Figure 3-21 shows, wind induced noise varied from a low of 88 dBA at 20 MPH to a maximum of 113 dBA at 70 MPH. The dotted lines show that the mean wind noise within the operator's ears measures over 100 dBA at 40 MPH. Since many small open boats are capable of speeds over 40, it may be assumed that operators are subjected to sound levels of this magnitude from wind alone.

A problem does exist from the standpoint of applying the data. If one looks at the total sound levels measured on boats being powered at similar speeds, the measured sound levels at the operator's stations are considerably less than those measurements for wind alone per the Howell study.

This creates many questions. How valid is the Howell data? Are wind-induced sound levels really that loud to the operator? Howell used a special type of microphone developed especially for the experiment that was planted inside the subject's ear. The data was modified somewhat to coincide with what the sound level would have been at the center of the subject's head if he were not there. Can this data be compared directly to data recorded on commercially available sound measuring equipment?

Normally experimentors use wind shields over microphones when measuring the sound level on moving vehicles to eliminate the effects of the wind passing over the microphone. Perhaps this isn't valid. Perhaps the perceived sound levels on moving vehicles are actually quite a bit higher than we now believe.

This area should be carefully studied since Howell's wind-induced noise levels were high enough to cause complete masking of reliable speech communication, temporary threshold shifts, permanent hearing losses if sustained for a long enough period of time, and possible other physiological problems.

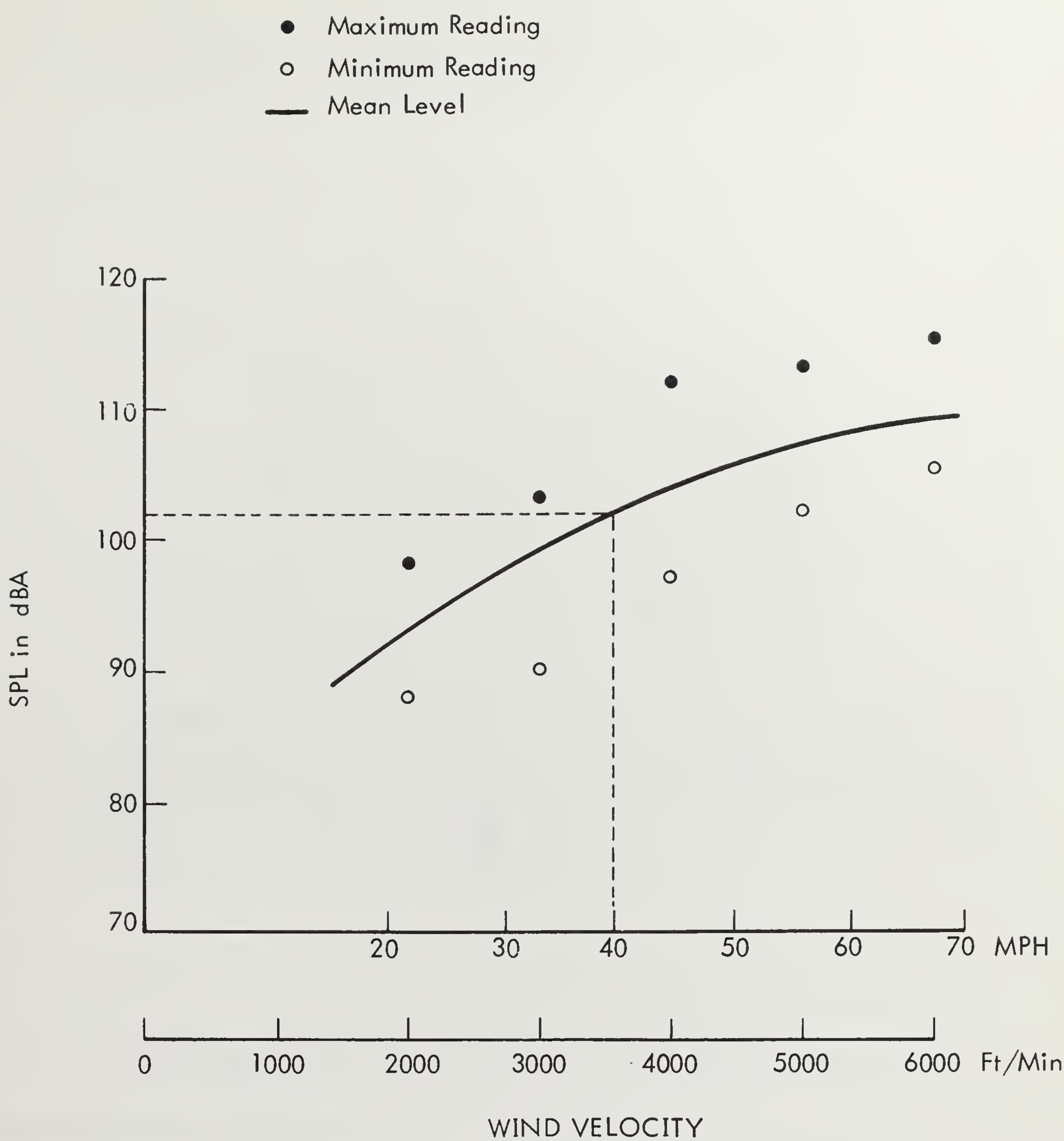


Figure 3-21. Noise Level Versus Wind Velocity

3.3.3.3 Summary - Noise

Two hundred eleven (211) sound level measurements made from the operator's position of all boats under power and referenced were combined and are presented in Figure 7-A below.

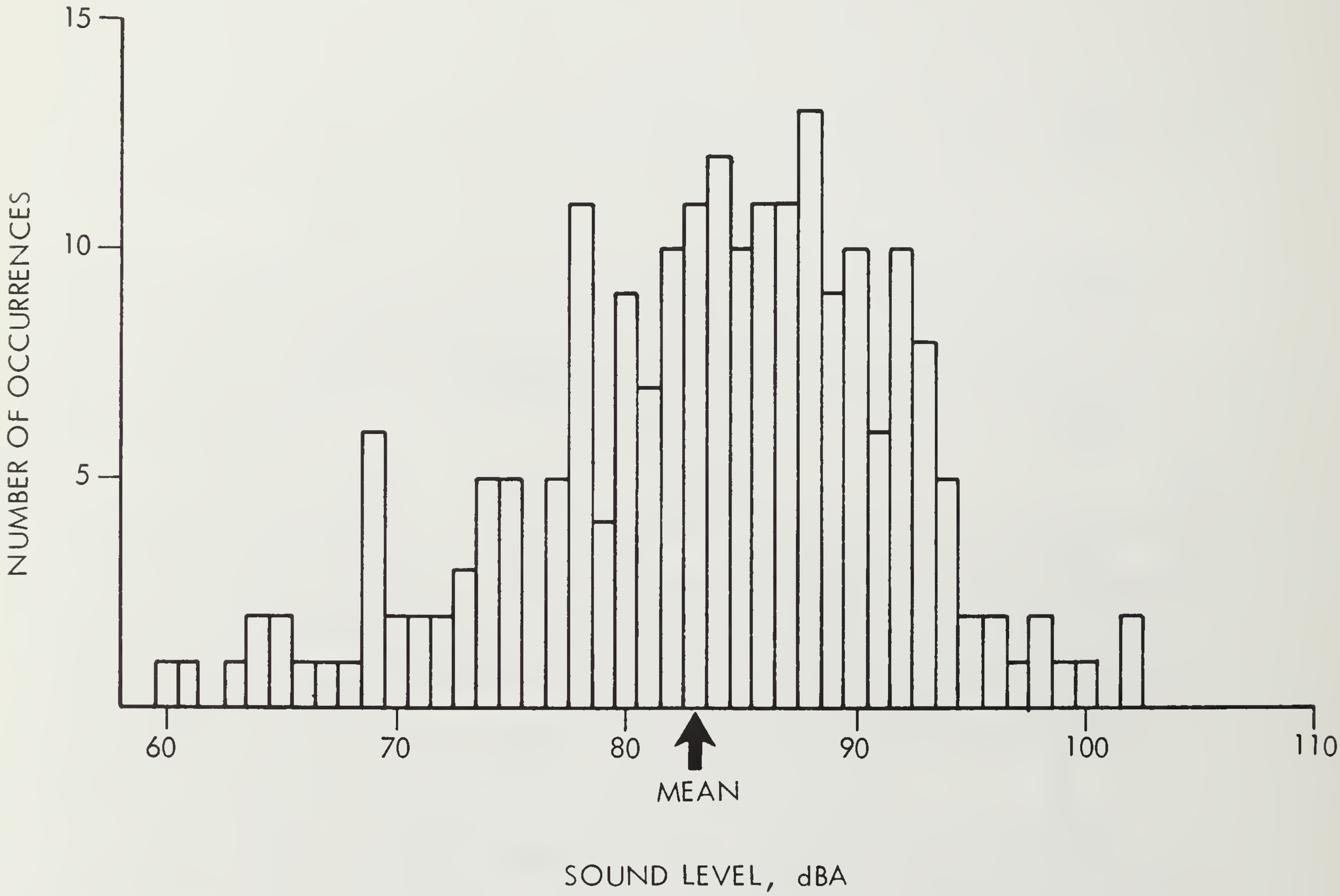


Figure 3-22. Frequency of Occurrences for Sound Levels

As can be seen, sound levels varied from 60 dBA through 102 dBA with a mean of 83 dBA. According to the referenced sources, a significant number of the data points fell with the range of sound levels that:

- mask effective speech communication.
- cause temporary threshold shifts.

- contribute to permanent hearing damage.
- may cause other physiological problems which could contribute to the cause of collisions.

More startling were the results of the experiments on wind-induced noise levels measured inside the human ear. If one can accept the results of the experiment as being valid, the noise that the operator of an open runabout travelling at 40 MPH hears from the wind passing his head is approximately 100 dBA. Obviously when water noise and machinery noise are combined with this, the resultant sound level that the operator actually perceives could be significantly higher. For example, if we have two similar noise sources operating simultaneously, the sound energy generated by the two sources will add together to give a value double that which would result from either source operating alone. The resulting sound pressure level in decibels from the combined sources will be only three decibels higher than the level produced by either source alone (since the decibel scale is logarithmic rather than linear). In other words, if we have two sounds of different magnitude, then the level of the sum will always be less than three decibels above the level produced by the greater source alone. If the two sound sources produce individual levels that are different by 10 decibels or more, then adding the two together produces a level that is not significantly different from that produced by the greater source operating alone.

How does all this effect the collision problem? If it can be proved that sound levels of the magnitude measured in the referenced studies actually degrade operator performance, a good case could be made to perform an indepth study of the noise problem as it relates to operator performance and physical and mental degradation.

The VAST apparatus described elsewhere in this document has already been used to demonstrate the effects of combined stressors on the boat operator's performance. A study should be designed using the VAST apparatus that would isolate the effects of various sound levels to determine their effects on operator performance. If found to be significant, sound level reduction techniques should be established, prototyped, and demonstrated.

3.3.4 Shock and Vibration

3.3.4.1 Introduction

When planing boats move over the surface of water that is anything other than smooth, the interaction of the water surface and the hull results in a certain amount of pounding and vibration. Both pounding (shock) and vibration can be defined as stressors to the human operator, and if severe enough or present for a long enough period of time can cause fatigue and can degrade operator performance.

Pounding or shock is defined as the rate of change of acceleration usually associated with short duration exposures such as might occur when crossing a wake or waves having a fairly long period. Vibration, on the other hand, is defined as the more constant rate of change in accelerations that are of higher frequencies. Vibrations are generally expressed in terms of their amplitudes and frequencies. In terms of this discussion they will be treated as one problem area and will be termed "vibration".

How much degradation occurs to the operator's performance due to normally encountered vibrations are at present undefined. In fact very little data exists on vibration levels within powerboats.

This section will look at the characteristics of vibrations that cause performance decrements and will present the results of a study designed to measure vibrations on operators encountered while boating under what could be termed as "normal" conditions.

3.3.4.2 Effects of Vibration on Human Performance

Miller (Reference 2) discusses shock separately from vibration. He concludes that little shock data exists that could be related to mechanical shock problems in small boats. Vibration data severe enough to be classified as over the threshold of human intolerability was measured on the bow of a boat. Miller claims that that fact alone makes further research into the vibration area a "matter deserving immediate attention".

According to Morgan, et al. (Reference 9) the human body appears to respond selectively to one of three vibration quantities over each of three portions of the range of 1-250 Hz. Between 1-6 Hz, the body responds primarily to the jolt component of the vibration, and is usually referred to as pounding or shock. Between 6-9 Hz, the body responds primarily to the maximum acceleration, and between 9-250 Hz the body responds primarily to the maximum velocity imparted by the vibration.

Very low-frequency, high-amplitude vibrations are the primary cause of motion sickness. Vibrations in the range of 1- 250 Hz can produce headaches and fatigue at the intolerable level. Permanent physical damage can occur when the exposure at the intolerable level is of sufficiently long duration. According to Morgan, et al., this is an important problem in the trucking industry where such vibrations are often found at intolerable levels. Prolonged exposure to vibrations of less than intolerable levels, though they may not produce physical damage, commonly produce annoyance and fatigue. These factors can be expected to reduce the general performance and effectiveness of the operator.

Morgan references studies that define the various resonant frequencies of body members. The resonant frequency of the body is between 2 and 5 Hz. The body is capable of attenuating a portion of the energy and the vibrations are increasingly attenuated as the frequency increases. In fact, above 8-10 Hz, the amplitude of body vibration is less than that of the vibrating platform. At 100 Hz the attenuation of the head is about 40 dB. The head, however, has its own resonant frequency in the area of 20 to 30 Hz. At 60 through 90 Hz, the eyeballs resonate. These phenomena are important when considering the complex visual task of the boat operator.

Dayton, et al., (Reference 18) references studies that define degradation in aircraft pilots' capabilities under various vibration frequencies and amplitudes. Figure 3-23 shows the ranges of physically disturbing vibration frequencies. Note that the arms are affected by vibration in the 2-8 Hz range and eyes in the 12-27 Hz range.

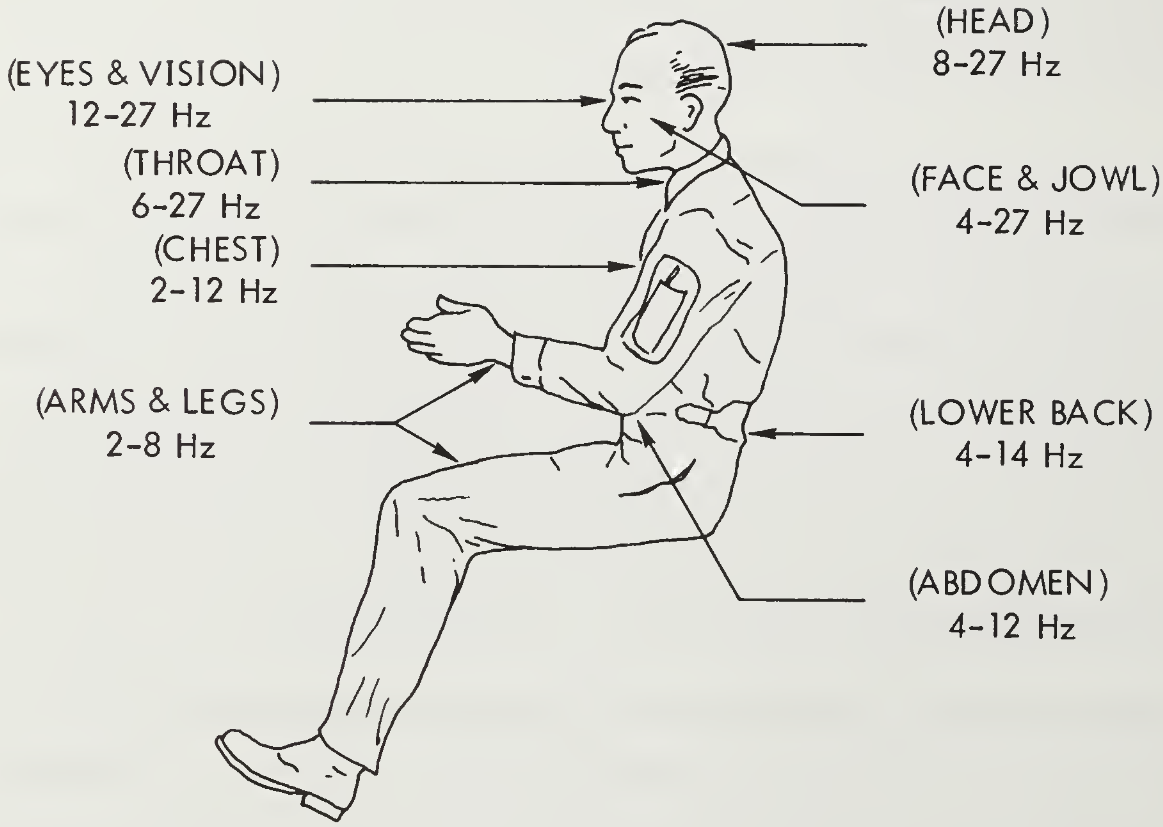


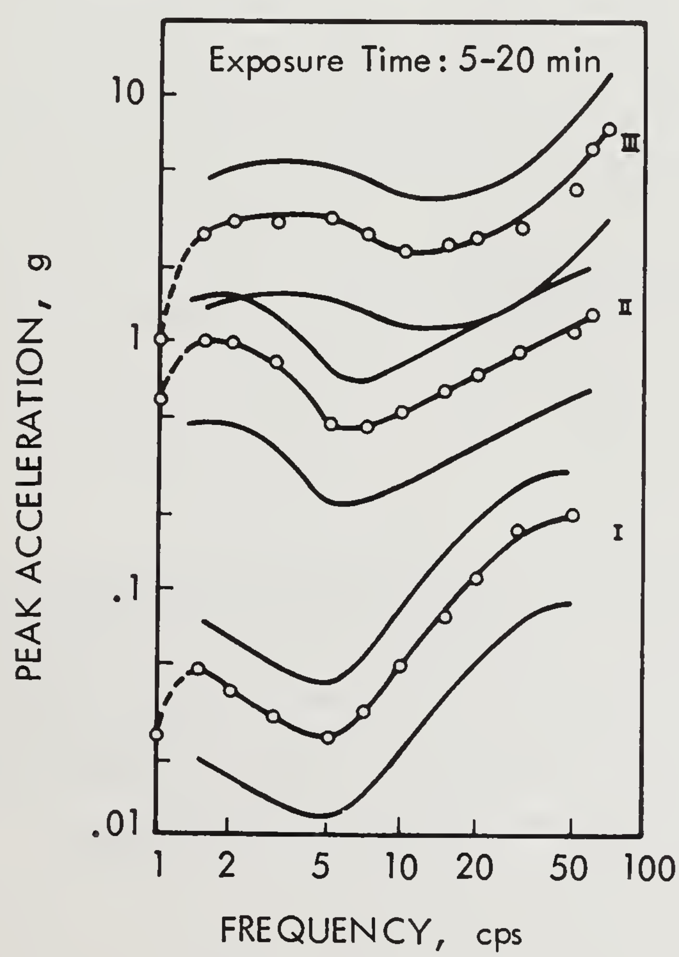
Figure 3-23. Concentrations of Disturbing Sensations and Ranges of Frequencies

One of the most important factors in human tolerance to boat vibrations when running in rough water or traversing wakes is the tolerance to vibration in the thorax-abdomen system. Here, organs are displaced moving the abdominal wall, diaphragm, and chest wall. The major resonance of the thorax-abdomen system is around 3 to 4 Hz.

Exposure to these types of vibration increases the energy expended in working and affects the general emotional response of the operator. These various effects are not fully understood and, therefore, only general statements can be made about them.

Human tolerances to vibrations have been plotted by recording the subjective feelings of subjects and include the ability of the subject to detect the presence of the vibration, feel discomfort and experience pain. Tolerance limits, therefore, are traditionally expressed in these terms.

The most widely referenced curve for human tolerance to vibration was created by Goldman (Reference 9) and is presented in Figure 3-24, below.



Average peak accelerations at various frequencies at which subjects perceive vibration (Curve I), find it unpleasant (Curve II), or refuse to tolerate it further (Curve III). Subjects were without body restraint. Shaded areas are about one standard deviation on either side of mean (Goldman, 1948).

Figure 3-24. Vibration Tolerance Criteria

Protection against vibration is achieved by reducing the applied forces or manipulating body posture. It is interesting to note that cushions are relatively ineffectual in the human resonance range and can even amplify vibrations at human resonance frequencies, although they are generally effective in damping higher frequency vibrations. Figure 3-25 (Goldman, Reference 9) shows this effect in terms of the mechanical impedance of a man on a seat.

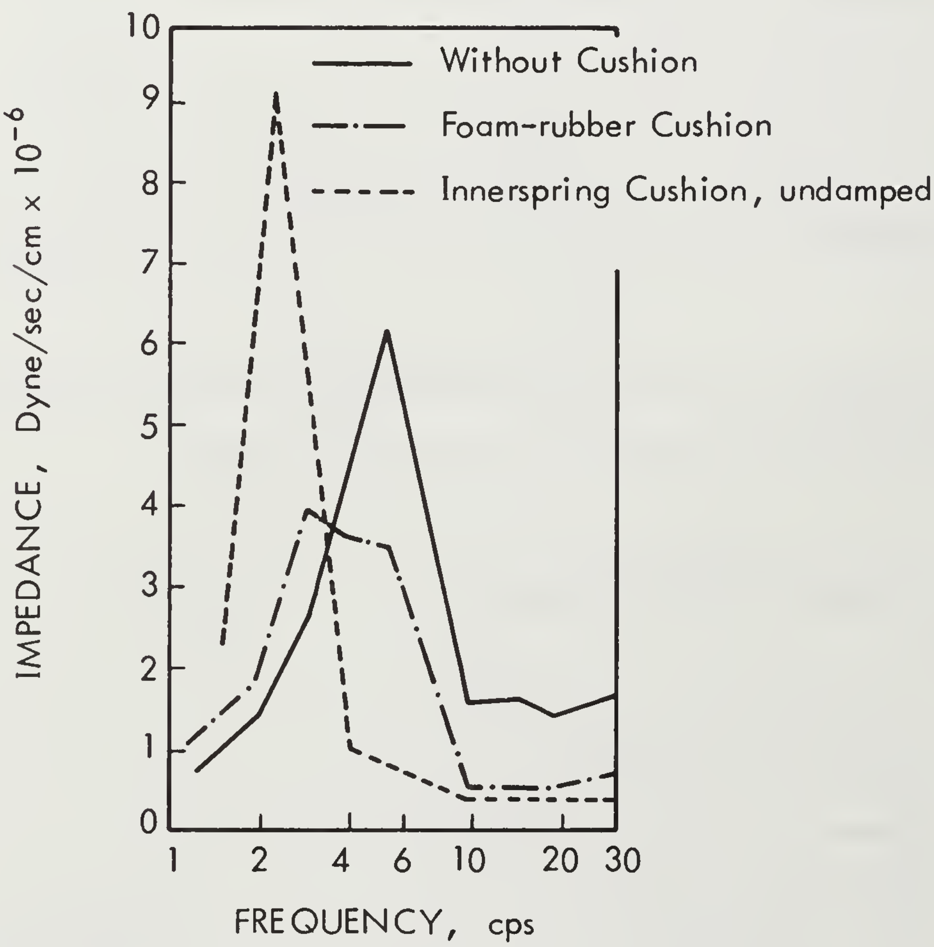


Figure 3-25.

Resonance can be seen at about 6 cps. The cushion dampened the system at higher frequencies but resulted in a resonance at lower frequencies. The undamped innerspring cushion actually resulted in an amplified resonance at a lower frequency. When low frequency vibrations are expected to be encountered, it appears as if normal cushions are ineffective. Thus cushions are used for static comfort and are effective in damping vibrations above the human frequency range.

According to Morgan, the most effective attenuator of vibration is the human's legs. For situations near intolerable levels, it is possible to develop special support devices that make the maximum use of body position and leg support. Those people that have been involved in ocean power boat racing have developed a special type of support device that is used in the standing position. Figure 3-26 shows such a device. Here the three-man crew are supported around the abdominal and lower thorax area. The legs are used to support the crew from vertical accelerations in the "plus" direction. The fact that each person can hold onto a stationary and strong hand hold helps to support them in the vertical "minus" direction.

The next portion of this discussion will deal with actual vibrations measured in boats and will apply those vibrations to the above data on human tolerances.

3.3.4.3 Vibration Data

Present vibration data consists of acceleration measurements made on some portions of the boat structure. Miller references acceleration data measured on the bow of a speedboat. Other references do not indicate where on the boat the vibrations were measured.

Since we are concerned with the effects of vibrations on human performance, it was felt that actual acceleration data should be measured on the boat operator. It was also felt that vibration extremes were not desired, but instead, those vibrations encountered in the course of normal boating activity should be measured. For that reason, Wyle measured the vibration levels on boat operators while they ran ten different boats under what could be termed as "normal" conditions.

<u>3.3.4.3.1 Data Collection Technique</u> — To measure vertical accelerations on the operator, an accelerometer was permanently attached to the inside of a specially made belt and was so positioned that when the belt was put on, the accelerometer would press against the operator's hip bone.

Figure 3-26. Power Boat Racing - Body Support Structure

In Section 3.3.4.2 various resonant frequencies of body members were noted. Most serious were the resonant frequencies of the head and those of the thorax-abdomen area.

If the operator vibrates with the 20 to 30 cps range of the resonant frequency of the head, his vision will certainly be adversely affected as will his blood circulation and possibly his overall performance. It is interesting to note that measured frequencies ranged from 10 through 40 cycles per second with most frequencies ranging in the 20 to 30 cps area. Therefore, at those frequencies the head will most certainly be vibrating at its resonant frequency and could cause some degradation in the operator's performance if the amplitude was high.

As can be seen from Goldman's table, accelerations ranged between 0.2 g and 1.2 g and averaged about 0.7 g. According to the table the majority of the data points fell within the area where Goldman's subjects felt that the vibration was unpleasant. Two measurements fell within the intolerable zone and all were above the level where humans perceive that vibration exists.

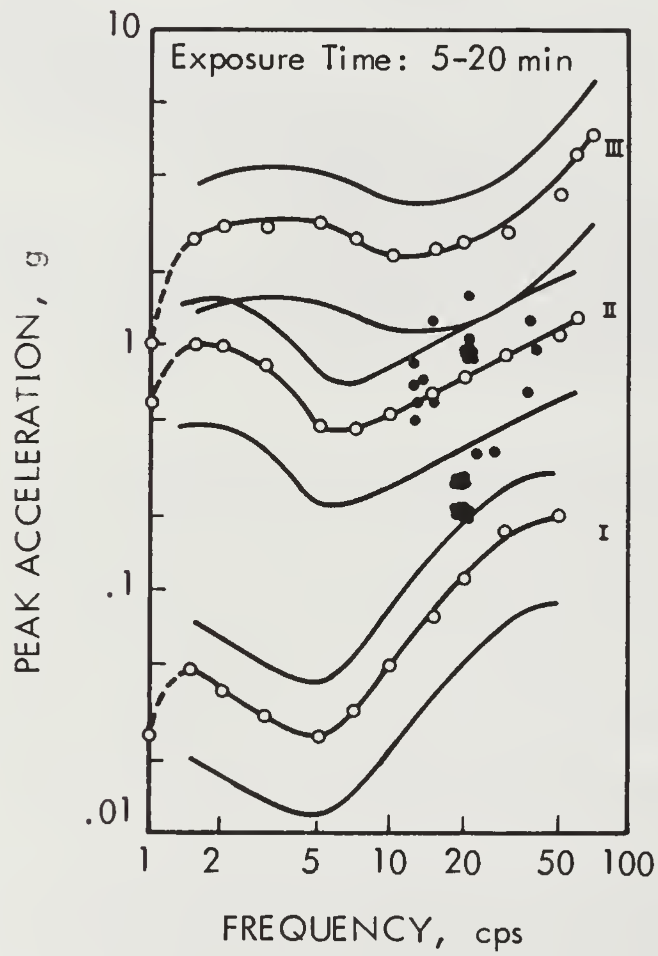
Because of the fact that most data points fell within the "unpleasant" zone, and are within the frequencies of whole head resonance, there is reason to believe that operator performance degradation could very well occur due to vibration.

All of the data points fall within or well above the ranges of physically disturbing vibration frequencies for arms (2-8 Hz) and eyes (12-27 Hz). In fact, the pilots used in these studies reported blurring of vision in this range. Operator performance would definitely be affected if he were unable to clearly see objects or other boats in the water (Dayton & Brady) Reference 18). According to Hornick (Reference 16), during the first Mercury flights the astronauts complained of vibrations during boost which interferred with their vision.

The effects to the boat operator remain unknown, but could result in headaches, poor blood circulation in the area of the brain (or throughout the body in general), nausia, etc. Although not known for certain, a loss in the ability to maintain proper balance has been suspected when humans are subjected to vibrations of this nature.

Acceleration data was recorded on an instrumentation grade tape recorder. The operators were asked to run their boats first in smooth water (less than a 6" chop) at idle speed, a comfortable cruising speed, and at wide-open throttle (WOT). Next they were asked to operate their boats in choppier water but to travel only as fast as they normally would if they had their family or guests aboard. We weren't looking for extremes but, instead, wanted to find vibration levels that boaters often encounter.

<u>3.3.4.3.2 Results</u> — Results are presented as they relate to the human tolerance data referenced in 3.3.4.2. Actual data points have been superimposed on to Goldman's vibration tolerance criteria table to demonstrate where pleasure boating vibrations fit in terms of human tolerance levels. See Figure 3-27, below.



Vibration tolerance criteria. Average peak accelerations at various frequencies at which subjects perceive vibration (Curve I), find it unpleasant (Curve II), or refuse to tolerate it further (Curve III). Subjects were without body restraint. Shaded areas are about one standard deviation on either side of mean (Goldman, 1948).

Figure 3-27. Boat Vibration Data
Applied to Vibration Tolerance Criteria

Since all measurements were made in the "normal" choppy water conditions that could be expected to be prevalent in lakes, rivers, and bays, the lower frequency vibrations encountered when a fast power boat crashes through ocean waves were not measured. It is known, however, that these types of waves produce vibrations within the resonant frequency range of the thorax-abdomen area. Ocean racing power boat restraint devices were mentioned in 3.3.4.2. Operators of these boats often experience severe pain and in the case of at least one race boat driver, internal bleeding is experienced for several days after each major ocean race. This means that his abdominal organs are being displaced to the point of major injury.

This example is extreme, of course, and is not considered to be a problem within the normal boating arena; however, it points out that some boats are capable of existing within that environment and, therefore, can produce those very dangerous frequencies and amplitudes to the unwary.

3.3.4.3.3 Conclusions — Vertical accelerations found in the "normal" boating environment fall within the range of the resonant frequencies of the head, and fall primarily within the acceleration range perceived as "unpleasant" by Goldman's subjects (Reference 9).

Performance decrements could very well result from vertical accelerations within the measured parameters. Unfortunately we need more information both on actual vibrations measured on people on boats and more information on the actual effects of those vibrations.

Further research is, therefore, recommended in this area. First we should measure accelerations on more boats to gain more confidence in the validity of our data bank, and second we should utilize the VAST apparatus to measure the effects of that spectrum of vibrations on operator performance.

3.3.5 Lateral Accelerations

3.3.5.1 Introduction

When a boat operator puts his boat into a turn, he is subjected to centrifugal force which tends to move him sideways within the boat. Large, fast boats are often designed with seats that prevent the operator from sliding sideways. However many are not. Smaller boats generally have bench type seats that would allow the operatoı to slide sideways for quite a distance.

How large are the lateral accelerations that boat operators could be expected to experience? And, what effect would these accelerations have on the operator's performance?

Wyle measured the lateral accelerations on nine small boats in an effort to determine if a problem exists and if so, to what extent.

3.3.5.2 The Study

Nine boats were run through a test course in relatively smooth water to determine their manuevering capabilities at various speeds (Reference 19). Turning maneuvers were made more and more difficult until the operator reached the point where he couldn't traverse the desired course. Lateral accelerations were measured during each maneuver. Minimum acceleration in terms of g's, mean accelerations, and maximum accelerations are shown in Figure 3-28.

All of the boats were of the runabout type and had cushioned seats with backs. None of the seats were of the wrap-around type, meaning that the operator could have moved sideways in the seat and in fact did so on some occasions.

The data doesn't seem to correlate the amplitude of the lateral accelerations with speed except for Boat No. 5 which did register over 3-1/2 g's at 51 MPH. However hull shape might be an important factor. It appears as if the boats having a moderately deep-V hull imparted less lateral accelerations to the operator. All accelerations were well below the point of being harmful from a physical standpoint. All accelerations were well below the point of being harmful from a physical standpoint. However, depending on what the frequencies may have been, various parts of the body could have been in resonance, which in case of the head could cause blurred visions, headaches, nausia, decreased blood

BOAT NO.	SPEED (MPH)	HULL TYPE *	MINIMUM	$\overline{X}$ of MEAN	MAXIMUM
1	36	Shallow V	0.457	0.956	1.806
2	43	Medium V	0.172	0.367	0.707
3	39	Shallow V	0.387	0.996	2.217
4	40	Shallow V	0.146	0.456	0.906
5	51	Deep V	0.650	1.341	3.535
6	35	Tri-Hull	0.397	0.850	1.356
7	40	Medium V	0.237	0.562	0.929
8	48	Medium V	0.058	0.435	0.913
9	39	Tri-Hull	0.207	0.618	1.134

* Shallow V = Deadrise $< 10^\circ$

Medium V = Deadrise $> 10^\circ < 20^\circ$

Deep V = Deadrise $> 20^\circ$

Figure 3-28. Lateral Accelerations Measured On Boats.

flow to the brain, etc. Whether any of the lateral accelerations were severe enough to actually cause these effects is unknown.

We do know, however, that lateral accelerations in the normal boating environment are severe enough to cause some boats to skip sideways on the water during a turn. A close look at Figure 3-16 will reveal that while negotiating the collision avoidance maneuver, the boat would visibly be displaced sideways in every third frame. This was probably due to the fact that there was a small wake travelling across the water at that time.

One of the contributing causes of a collision that was investigated in-depth and presented as Case #2 in Volume II of this report was the fact that the flat hulled john boat slid sideways while attempting to negotiate a turn at a high rate of speed. He ended up on the left side of a channel and a collision ultimately resulted.

We have measured lateral accelerations during turning maneuvers on boats. However, many questions remain. How often are these accelerations encountered? How do they contribute to overall operator fatigue? How often do operator's slide sideways or have to concentrate on bracing themselves so they do not? What effect does this have on the steering capacilities of the operator? What effect does hull shape have on lateral accelerations imparted to the operator?

3.3.6 Control Station Survey

3.3.6.1 Introduction

As we have said throughout this document, about 90 percent of the causes of collisions have been attributed to human failure. Our problem is to determine what caused the human to fail. This section will deal with human engineering considerations within the operator's control station not covered in the preceeding portions of Task III. Physical relationships of various components of control stations will be compared to human engineering data to determine if there is a problem which could affect the performance of a boat operator.

The automotive industry, aircraft industry, and the military all have very complete design standards for the location of control station components. Techniques for locating components consist basically of determining the size of 90 (or 95) percent of the expected user population (5 (or 2-1/2) percent at both extremes are excluded), performing task analysis to determine use frequencies of the components, performing time line analysis to determine placement envelopes for various items that must be manipulated simultaneously, and locating components to the best compromise of the most important criteria.

Unfortunately, this expertise does not exist in the boating industry. Instead, boats are designed more or less by tradition and by what components are readily available and for how much. Manufacturers cannot be severely criticized for this, however, since no one manufacturer is large enough to employ the staff of human factors personnel that it would require to develop and implement the standards. In addition, there has been no pressure put on the manufacturers by their customers to spend more money to develop better control systems or control stations.

Because there are no design standards, how far astray has the industry gone? How bad is the human engineering problem within the control station area? The remainder of this section will deal with:

- defining the types of control stations
- defining applicable human engineering design standards or data, and

- comparing the human engineering data to actual control stations.

3.3.6.2 Types of Control Stations

Generally speaking, there are four types of control stations associated with power boats.

The first can be defined as the lack of a control station. This is the boat that is small enough or uses a small enough motor to be controlled directly from the motor. The operator generally sits on a thwart just forward of the transom, turns to the left slightly and steers the outboard with his left hand. Because of the fact that a control station as such doesn't really exist in this type of boat, it will not be considered as part of this section.

The second type of control station is found in most runabouts, bass boats, bowriders, speedboats, and flying bridges on cruisers. The seat/wheel configuration is generally patterned after the automobile and, as such, is designed for sit down operation.

The third type of control console is found on many center console boats and on some of the flying bridges on large cruisers. The boat is designed to be operated from either the stand up or sit down position. Generally, an automotive style wheel is used and is mounted at an angle that is most convenient for stand up operation.

The fourth type of control console is found on cruisers. Traditionally, a large diameter wheel is mounted to a bulkhead in the vertical position at a height that is convenient for stand up operation. Controls and displays are mounted on the deck forward of the wheel. Many times a folding seat or high stool is provided for sit down operation.

Each of these types of control stations will be treated separately when compared to applicable human engineering standards.

3.3.6.3 Runabouts

Directly applicable standards exist for the control stations found in runabouts since they are directly related to automotive control stations. However, since no other vehicle is designed with either the controls located behind the operator as in the small outboard powered boat or

for stand up and sit down operation as in the center console boats and cruisers, directly applicable design standards don't exist for these types.

Rather than utilize the various SAE Standards for seats, eye positions, reach distances, etc., along with anthrometric data from various human engineering data sources to critique the control stations, a newly developed design tool was used that incorporated much of the existing data into one, easy to use device. It is called "Humanscale 1/2/3" and was developed by Diffrient, Tilley and Bardagjy in conjunction with Henry Dreyfuss Associates and consists of pictorial selectors equipped with rotary dials which present over 20,000 bits of information on anthropometry and seating guidelines. (Ref. 7.)

Other sources of human engineering data are referenced, however, throughout this section in areas not covered in Humanscale.

3.3.6.3 Runabout Control Stations

Twelve runabout control stations were measured. They were selected from a group of boats ranging in length from 14 to 19 feet and consisted of outboard and inboard runabouts, bow-riders and bass boats. Each was selected because it represented a "normal or typical" control station as opposed to representing an out of the ordinary or very bad example.

Measurements taken included dimensions and angles and are shown in Figure 3-29.

The control station was considered in profile, then in plan, or more explicitly, from the side, then from the top. The seat reference point (SRP) or the intersection of the depressed seat cushion and the depressed back support was used as the reference point for almost all measurements in profile and included:

1. Eye envelope
2. Seat configurations
3. Reach distances (wheel location, controls)
4. Leg clearances
5. Knee clearances

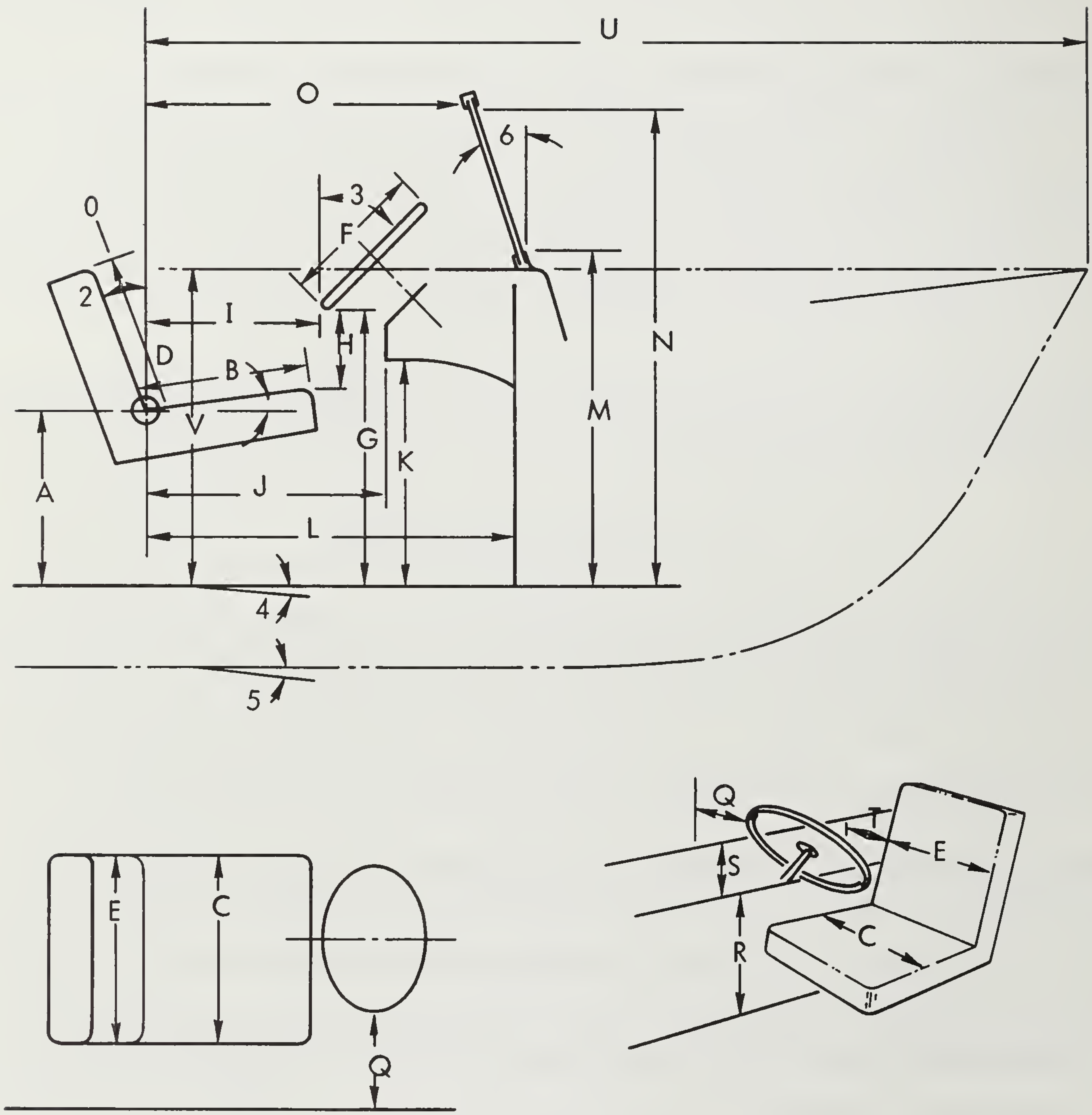


Figure 3-29. Measurements Taken in Control Station Study

The intersection of the centerline of the seat cushion and the SRP was used as the reference for all measurements in plan.

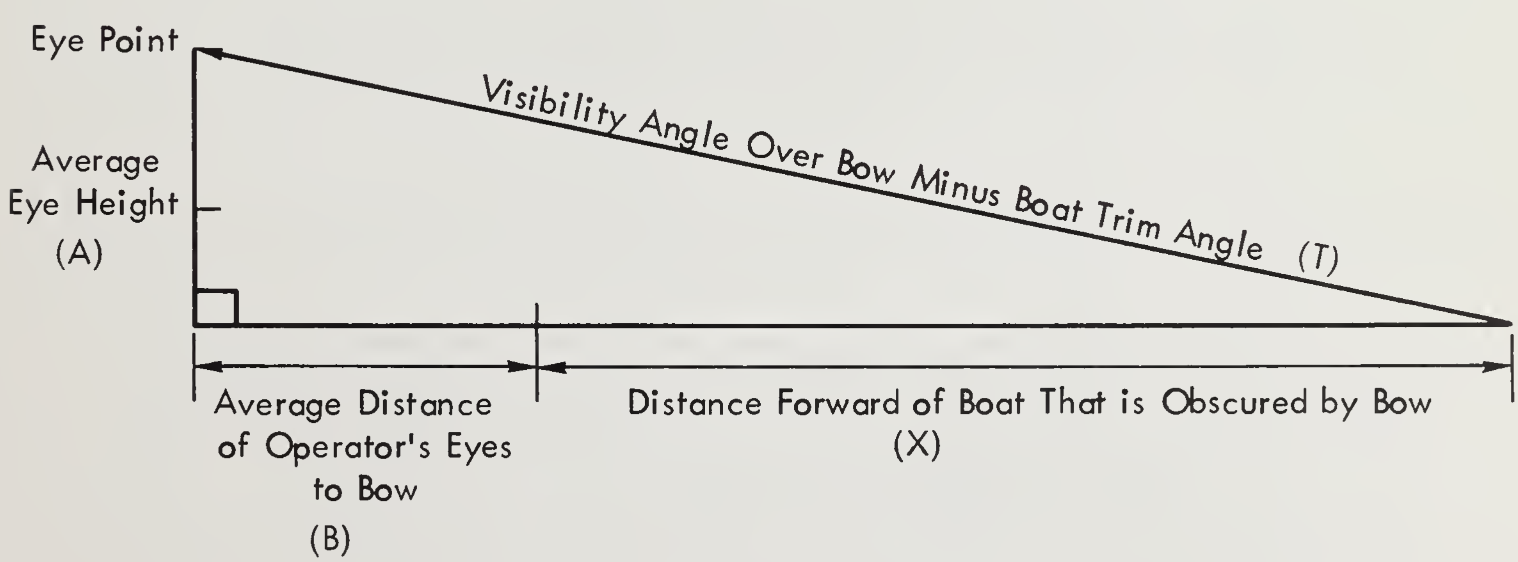
3.3.6.3.1 Eye Envelopes — When the operator sits on or in the seat and rests his or her back against the back rest, the eyes come to rest in a certain area which can easily be calculated if one knows the anthropometric data for seated male and female eye heights and the seat back angles. Miller (Reference 2) presented the information in three easy to use tables that are shown on the following page (Figure 3-30). First, the small and large persons eye height above the SRP is determined, then the horizontal distance fore or aft of the SRP is determined. The result is two accurately placed eye points that encompass the size range of adult drivers. From those eye points, the forward visibility can be assessed.

ABYC (Reference 8) states that boat operators should be able to see the water 100 feet in front of their boat in order to see and safely avoid running over objects ahead of them.

This spelling can be approximated if the visibility angle to the bow is known, the running angle of the boat is known and the operator eye height off the water is known.

Running angle measurements and eye height measurements were taken as part of the visibility study in 3.3.1. In order to get an idea of the visibility over the bow in the 12 runabouts and bowriders measured, the average eye height and average trim angle and average operator eye distance aft of the bow were used as inputs in the following calculation:

$(\text{TAN } \theta - T)A - B = X$ Where θ, A, B, T, and X are:



Seat Back Angle (0) (degrees)	Eye-Point Height Above Seating Reference Point (inches)
5	27.1
6	27.1
7	27.1
8	27.1
9	27.1
10	27.1
11	27.0
12	27.0
13	27.0
14	26.9
15	26.9
16	26.8
17	26.7
18	26.7
19	26.6
20	26.5
21	26.4
22	26.3
23	26.2
24	26.1
25	26.0

Seat Back Angle (0) (degrees)	Eye-Point Height Above Seating Reference Point (inches)
5	32.6
6	32.6
7	32.6
8	32.6
9	32.6
10	32.6
11	32.5
12	32.5
13	32.5
14	32.4
15	32.4
16	32.3
17	32.2
18	32.2
19	32.2
20	32.0
21	31.9
22	31.8
23	31.7
24	31.6
25	31.5

Seat Back Angle (0) (degrees)	Fore and Aft Eye-Point Location* Referenced to the SRP (b) in Inches
5	7.8
6	7.3
7	6.8
8	6.3
9	5.8
10	5.3
11	4.8
12	4.4
13	3.9
14	3.4
15	3.0
16	2.5
17	2.0
18	1.6
19	1.1
20	0.7
21	0.3
22	-0.2
23	-0.7
24	-1.0
25	-1.4

* Negative sign indicates eye-point location aft of the Seat Reference Point (SRP).

Figure 3-30. Seated Eye Point Determination Tables

The following results were obtained:

Boat Number	Obscured Visibility Distance	Meets ABYC Standard
1	75 ft	Yes
2	63 ft	Yes
3	261 ft	No
4	46 ft	Yes
5	46 ft	Yes
6	41 ft	Yes
7	32 ft	Yes
8	36 ft	Yes
9	29 ft	Yes
10	92 ft	Yes
11	24 ft	Yes
12	36 ft	Yes

Considering that ABYC recommends that the maximum obscured distance be 100 feet, only one boat in twelve didn't meet it. The average obscured visibility distance from the bow was, in fact, only 58 feet. One could conclude that the visibility from this small sample of runabouts and bowriders was, on the whole, quite good as compared to ABYC Standards.

3.3.6.3.2 The Seat — The seat itself was the next item to be critiqued on the twelve runabouts. Since all other components within the control stations were to be related back to the seat reference point (SRP), it was felt that the seat was probably the most important component within the runabout control stations with the seat/wheel relationship being the most important component relationship.

Since no standards exist for seats on boats, the seat cushion angle and cushion to backrest angle of automotive, industrial, and aircraft seat standards were compared and plotted on Figure 3-31. The proposed acceptable area was pulled out and separately plotted (See Figure 3-32.

The seats in the twelve runabouts were measured and compared to Figure 3-33 with the following results:

Boat Number	Seat Within Acceptable Range
1	Yes
2	Yes
3	No

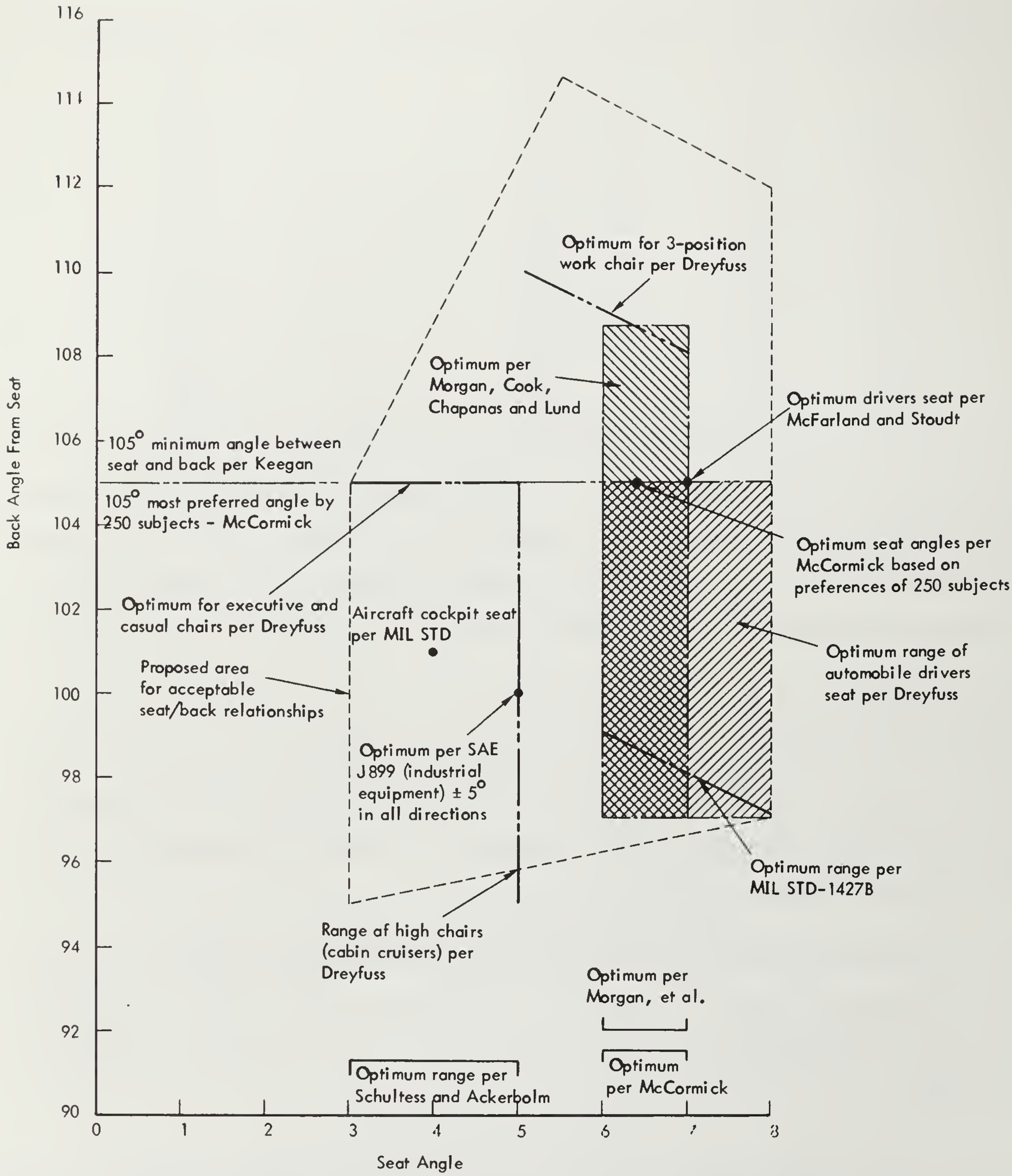


Figure 3-31. Seat Pan Angle vs. Backrest Angle

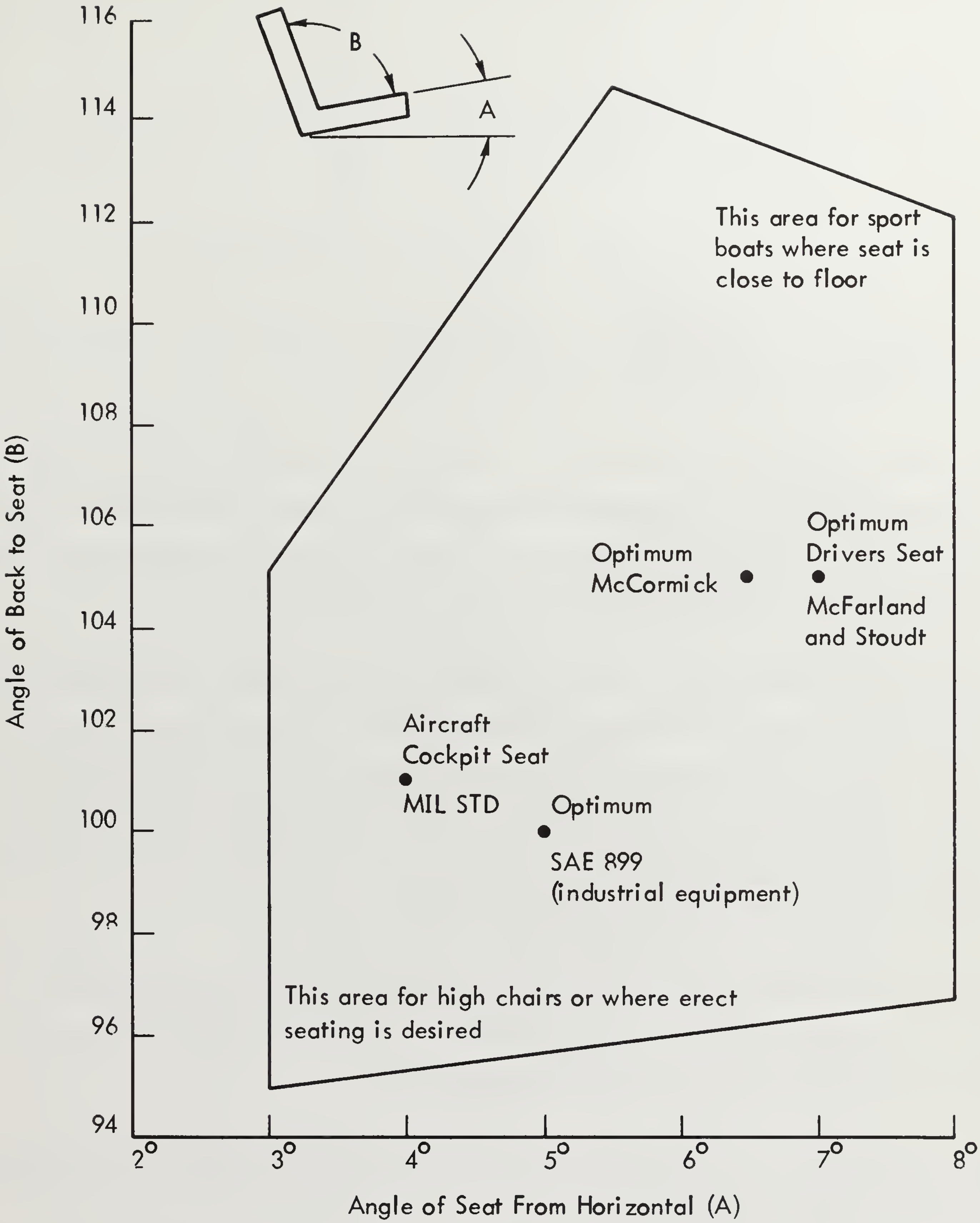


Figure 3-32 . Range of Acceptable Seat Angles

Boat Number	Seat Within Acceptable Range
4	Yes
5	Yes
6	No
7	Yes
8	No
9	No
10	Yes
11	No
12	No

Six seat configurations or 1/2 of those measured fell within the acceptable area. Those that didn't failed because of inadequate seat cushion angle. In fact, one seat cushion was angled 4° in the wrong direction.

What effect does this have on the operator of the boat? He will tend to slide forward, out of the seat, and will have to make an effort to brace himself, usually with his feet, to prevent his buttocks from sliding forward. Since the extra task of bracing uses energy, it could effect this fatigue level and, hence, contribute to the collision problem.

3.3.6.3.3 The Steering Wheel — The location of the steering wheel in relationship to the seat was the next parameter considered. Humanscale (Ref. 7) shows the horizontal distance from the SRP to the bottom edge of the wheel to be between 9.5 and 15.5 inches depending on where the seat is adjusted in the fore/aft range. Since most runabout seats have no fore/aft adjustment, these numbers are somewhat meaningless. The vertical distance from the SRP to the bottom of the wheel was shown as 10 to 11 inches.

ABYC Standard H-1 (Ref. 17) recommends a 23 to 25 inch distance from the center of the wheel hub to a point somewhere around the middle of the backrest and a 7 to 11 inch vertical distance from the seat cushion to the bottom of the wheel.

ABYC's horizontal distance to the center of the hub corresponds to an 18 to 21 inch distance from the SRP to the wheel bottom.

Morgan, et al. (Reference 9), states that the minimum horizontal SRP to wheel distance should be 13.5 inches for lightly clothed people and 15 inches for heavily clothed people.

Dreyfuss (Ref. 10) sets the minimum seat back to wheel distance at 15 inches. SAE J898 shows the area of optimum hand control areas for construction and industrial equipment to be 16 inches to 26 inches from the SRP in the horizontal plane and 8 to 18 inches from the SRP in the vertical plane.

When considering all of the above standards in an effort to find the acceptable range of wheel locations for runabouts, one must consider the following:

- The seat is probably not adjustable.
- The operator may be wearing a PFD.

Because the large person must be accommodated and because he may be wearing a PFD, the wheel to seat back distance on the runabouts should probably be at the outer extreme of the referenced acceptable ranges.

The present ABYC standard converted to wheel bottom measurements seems to be within the most reasonable range of all of the references and was used as the acceptable range criteria to judge the twelve runabouts. ABYC's vertical dimensions seemed to be within the range of the other references with the exceptions of the low end. If the wheel were only seven inches from the seat cushion, some large people would have a problem fitting their legs under the wheel. For that reason, the range of acceptable vertical measurements from the SRP to the bottom of the wheel were reduced from ABYC's 7 to 11 inches to 8 to 11 inches. The table below shows how the twelve boats faired in the wheel to seat relationship.

Boat Number	Horizontal SRP to Wheel Range 18 to 21 Inches	Vertical SRP to Wheel Range 8 to 11 Inches	Combined
1	No - Too Close	Yes	No
2	Yes	No - Too Low	No
3	Yes	No - Too Low	No
4	No - Too Close	Yes	No
5	Yes	Yes	Yes
6	No - Too Close	No - Too Low	No
7	No - Too Close	Yes	No
8	No - Too Close	Yes	No
9	Yes	Yes	Yes
10	No - Too Close	Yes	No
11	Yes	No - Too Low	No
12	No - Too Far	Yes	No

The wheel/seat relationship fell within the acceptable range in only two of the twelve boats that were measured. It is interesting to note that both parameters were out of the acceptable range in only one case. In most cases, in fact, the ones that were out, were out by only a small amount.

The steering wheel to seat relationship must be considered to be important because the steering wheel is the most important control mechanism that the boat operator uses. If this control is out of the acceptable location range, it could be more difficult to use and, therefore, contribute to fatigue.

3.3.6.3.4 Knee and Foot Clearances — Knee and foot clearances are important from the standpoint of comfort, fatigue and injury. If one's knees hit the underside of the control console, injury could result. Too much foot room can lead to lack of support in rough water. Too little foot or leg room is uncomfortable and can force one's knees up into the wheel.

Humanscale (Ref. 7), Morgan et al. (Ref. 9), and Dreyfuss (Ref. 10) were consulted as to knee and foot room with the following results. Morgan said minimum knee clearance should be 26-1/2 inches from the SRP. Twenty-five through 27 inches was referenced in Humanscale and Dreyfuss.

These numbers are only valid if the edge of the control console is less than 27 inches from the floor. If greater than 27 inches, one's legs can safely pass under the console without knee contact. The twelve boats were measured with the following results:

Boat Number	Greater Than 27" Horizontal Clearance	Greater Than 27" Vertical Clearance	Adequate Clearance
1	No	No	No
2	Yes	No	Yes
3	No	No	No
4	No	No	No
5	Yes	No	Yes
6	No	No	No
7	No	No	No
8	No	No	No
9	Yes	No	Yes
10	No	No	No
11	No	No	No
12	Yes	No	Yes

3.3.6.3.5 Foot Room — Foot room was more difficult to determine since it depends on seat height. The lower the seat, the more foot room is needed. Figure 3-33 was constructed by graphing the available data from the various human engineering design guides.

Foot room on the twelve boats was measured and is presented below.

Boat Number	Foot Room Adequate
1	No
2	No
3	No
4	No
5	No
6	No
7	Yes
8	No
9	No
10	No
11	Yes
12	Yes

Three of the twelve boats had adequate foot room. Since only four of the twelve had adequate knee room, knee and foot room may be a problem and may cause fatigue and irritation due to constant knocking of the legs or knees against the lower edge of the control console or inadequate foot room. Figure 3-34 shows a 95th percentile male sitting at the control console of one of the boats. Note that inadequate foot room has forced his knees up against the wheel and inadequate knee clearance has induced shin contact against the lower edge of the control console.

3.3.6.3.6 Shift and Throttle Controls — Most outboard boat manufacturers provide a place for the shift and throttle controls to be placed. This is generally a mounting board just below the coaming and outboard of the seat. The dealer or the owner mount the control mechanism at the time of motor installation. Two problems generally develop. The shift handle to wheel clearance is inadequate, see Figure 3-35, and/or there is insufficient clearance between the seat back and the coaming for the lower part of the arm when shifting into or advancing the throttle in reverse (see Figure 3-36). Another problem that occurs, but less often, is insufficient

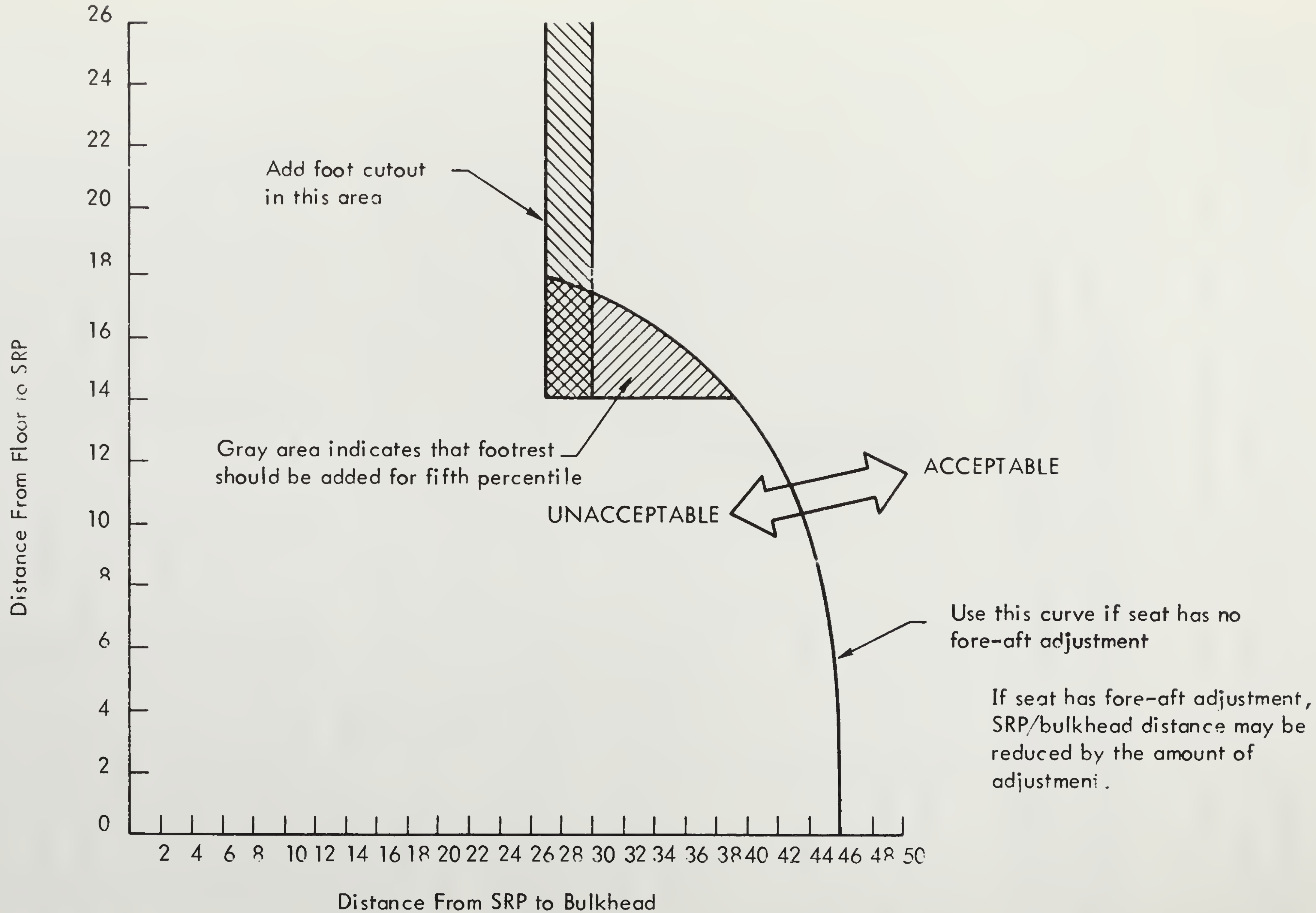


Figure 3-33. Minimum Bulkhead to SRP - Horizontal Distance

Figure 3-34. Leg Room Problems

Figure 3-35. Inadequate Shift Handle to Wheel Clearance

Figure 3-36. Inadequate Elbow Clearance

hand clearance between the throttle handle and the control console in the fast forward position.

Specific standards do not exist in these three areas; however, good human engineering practice dictates that no controls should be placed within two inches from the wheel to avoid accidental activation. When a representative sample of controls were measured, it was noted that most handles protruded about four inches from the coaming. Therefore, if the wheel to coaming distance was six inches or more, there would be little chance of control handle to wheel interference.

In order to pass one's elbow between the seat and coaming when shifting into reverse, there should be a minimum of five inches of clearance. This is based on Air Force authropometric data with another one-half inch added for clothing (Ref. 11).

The twelve boats were compared to the above recommended practices with the following results:

Boat Number	Greater Than 6" Wheel to Coaming Distance	Greater Than 5" Seat to Coaming Distance
1	Yes	No
2	No	No
3	No	Yes
4	No	No
5	No	Yes
6	No	No
7	No	No
8	No	No
9	Yes	No
10	No	No
11	No	Yes
12	N/A	N/A

Again, the boats didn't fair too well. Only two boats had adequate wheel to coaming clearances and only three boats had adequate elbow clearance to shift into reverse. Accidental activation of the throttle handle due to insufficient wheel clearance could be dangerous as could the extra time needed to change arm position to shift into reverse in a panic situation.

3.3.6.3.7 Conclusions - Runabouts — Only the basic static human engineering design parameters have been critiqued in this section. Not discussed because it was deemed to be out of the scope of Phase I were such factors as:

1. Reach envelopes
2. Visual access to displays
3. Coding of controls
4. Functional groupings
5. Task and time line analysis

Analysis of these types will tend to reveal whether the operator can reach all of the controls, whether he can see them, if they are coded in such a way that he knows what they are, and if they are located in such a position that he can operate them in the dynamic boating situation. In this case operation is measured against a time base. For instance, do three controls have to be operated at the same time and are they all located on one side of the operator?

Results of the basic human engineering evaluation have been summarized in the table below.

Boat #	Visibility Dist Meets ABYC Standard	Seat Within Acceptable Range	Wheel/Seat Relationships	Adequate Knee and Foot Clearance	Adequate Foot Room	Adequate Wheel to Coaming Dist. for Controls	Adequate Seat to Coaming Dist. for Elbow	% of Yes
1	Yes	Yes	No	No	No	Yes	No	[illegible]
2	Yes	Yes	No	Yes	No	No	No	43
3	No	No	No	No	No	No	Yes	14
4	Yes	Yes	No	No	No	No	No	29
5	Yes	Yes	Yes	Yes	No	No	Yes	71
6	Yes	No	No	No	No	No	No	14
7	Yes	Yes	No	No	Yes	No	No	43
8	Yes	No	No	No	No	No	No	14
9	Yes	No	Yes	Yes	No	Yes	No	57
10	Yes	Yes	No	No	No	No	No	29
11	Yes	No	No	No	Yes	No	Yes	43
12	Yes	No	No	Yes	Yes	N/A	N/A	43

Possibly, the sample of 12 runabouts, bowriders, and bassboats could not be termed as a representative sample of those types of boats on the market, but the fact that only 38 percent of the parameters that were measured met the established criteria shows that there are definitely problems in this area.

How much actual operator performance degredation can be attributed to poor runabout control station design as yet has not been measured; however, it could be considerable. The problem needs to be further researched.

3.3.6.4 Center Console Boats

In runabouts, the control station is designed around the seat because the operator is supposed to sit while driving. However, the operator may stand or sit while driving in many of the center console type boats. For that reason, the importance of the seat is lessened and the importance of the standup/sitdown relationship of the operator to the wheel becomes of primary importance with emphasis placed on the standup operation because it is the mode of operation used when docking or in critical situations.

Wyle measured three center console type boats and subjected them to a similar evaluation as described under runabouts in Section 3.3.6.3 above. Two of the boats were of the fishing variety and were obviously designed for standup, sitdown operation. However, all three boats were well within ABYC limits when the operator stood up. The problem with the third boat was simply that the seat was mounted too low. In fact, the same problem occurs with many models of this type of boat because the seat performs the dual purpose of a helmsman's seat and a fishing seat when turned to face aft. Problems would result if the seat were mounted high. The fisherman would have inadequate foot support. Since this can be noticed in the showroom and visibility over the bow can't, it sometimes assumes more importance from the manufacturer and dealer standpoint.

<u>3.3.6.4.2 Standup Operation</u> — When standing, is there enough room between the seat and the wheel? Are the wheel and the controls within a comfortable reach envelope? The three boats were evaluated against these questions.

Since no other vehicle is operated from the standup, sitdown positions, human engineering standards don't exist in this area and must be created for the purpose of evaluating the boats.

In terms of a horizontal wheel to seat clearance, one large cruising boat manufacturer has traditionally used 9 inches as their standard for cruisers. However, in cruisers the wheel and seat are at the same height. When the boat trims up by the bow, the helmsman may move his feet back for support or lean against the seat which is approximately at his buttocks. The lower seat of the center console boat hits the helmsman at the back of his knees and, therefore, could cause him to lose his balance and fall backward in the pitchup attitude. For that reason, more room is needed between the wheel and seat. Optimum spacing should be derived through experimentation; however, for the purpose of a preliminary evaluation, 12 inches has been chosen as being the minimum acceptable horizontal space between the wheel and seat for adequate standup operation.

The same problem exists for standing wheel height. No standards exist. Therefore, anthropometric data was used to derive an acceptable range of wheel heights. Judgement had to be used since one wheel was essentially vertical and the other two were tilted. Where on the wheel should one be able to reach — The top of the rim? The center measured horizonally? The bottom? For lack of any criteria, the center of the wheel was arbitrarily chosen as the place on the wheel where all measurements would be taken.

Based on anthrometric data from Humanscale (Ref. 7), Morgan, et. al. (Ref. 9), and McCormick (Ref. 12), the lower limit of the center of the wheel was placed at 30 inches from the floor. An upper limit for the standing operator was not designated since wheels would never come close to approaching it. The upper limit, instead, must be based on the seated operator's ability to control the wheel and see over it.

Wheel seat relationships and wheel height are shown below for the 3 center console boats.

Boat #	Wheel/Seat Dist > 12"	Wheel Height > 30"	Meets Criteria
1	Yes	No	No
2	Yes	Yes	Yes
3	No	No	No

In one case the wheel was too low and there was insufficient space between the wheel and the seat, and in one case both parameters were well within the acceptable range.

Since standup operation on boats of this type is commonplace for critical operations, the location of the wheel and the ability to stand behind it become quite important. Two out of three boats failed to meet the established criteria. Poor location of these items may contribute to operator failure and hence, may contribute to the collision problem.

3.3.6.4.2 Sit Down Operation

The seat/wheel relationship and leg room behind the console were evaluated. Seat/wheel criteria were established in 3.3.6.3.3, above. Knee room and foot room criteria were established in 3.3.6.4, above. The three center console boats were evaluated against that criteria with the following results.

Boat #	Horiz SRP to Wheel - 18 to 21"	Vert SRP to Wheel - 8 - 11"	Combined	> 27" Horiz. Clearance	> 27" Vert Clearance	Adequate Clearance
1	No	No	No	Yes	Yes	Yes
2	No	Yes	No	Yes	Yes	Yes
3	Yes	No	No	Yes	N/A	Yes

All three boats failed to meet the seated steering wheel to seat location criteria, but did meet the leg clearance criteria The problem here is that the seats are mounted too far back. In order to have standing room behind the wheel, the seat must be mounted so far back that reaching it while seated becomes a problem. If the seat were moved foreword, knee and foot clearance would diminish and probably become unacceptable. A sliding seat appears to be one solution to the problem.
This area requires more research. A compromise design solution certainly can be reached and should be derived from performance measurements in the standing and sitting mode.

3.3.6.4.3 Control Reach

Because both the top mount and side mount controls are useable with the center console boats, and because the dealer or owner installs them, it is impossible to evaluate the effects of their

location since they can and are located almost anywhere.

Standards should be developed and that would identify an acceptable range of control locations, directions of movements, and display locations. Until that time, only specific dealer/owner installations can be evaluated.

In the more rare I/O installations, the deck mount control handles are used and are universally mounted beside the wheel, usually on the right. For that reason, they can be evaluated using the same criteria as the wheel in 3.3.6.4.2, above.

<u>3.3.6.4.4 Conclusions — Center Console</u> — Results of evaluating the visibility, standup, and sit down criteria appear below.

Boat #	Meets ABYC Vis. Formula	Standup — Wheel/Seat Dist > 12"	Standup — Wheel Height > 30"	Seated — Seat/Wheel Relationship	Seated — Knee/Foot Clearance	Meets All Criteria
1	Yes	Yes	No	No	Yes	No
2	Yes	Yes	Yes	No	Yes	No
3	No	No	No	No	Yes	No

None of the boats passed the established criteria for acceptable human engineering control station design. A lot of work is needed in the area of establishing a compromise design solution between the standup and sit down operator control/display relationship.

The operator tasks should be studied in each mode as well as in the "down" modes from the control station stand point. For instance, the helmsman's seat may be used as a fighting chair while fishing. This must be taken into consideration and compromises made.

Performance decrements should be measured in a dynamic environment with controls placed in various locations in an effort to establish an acceptable control envelope for future standards applications.

3.3.6.5 Cruisers

Because cruisers form only a small percentage of the overall boat population, only two were used in this evaluation. The two chosen were new 1974 models found on the showrooms of two dealers in the Huntsville, Alabama, vicinity. They are major brands and are quite typical of the growing number of small trailerable cruisers available on the market.

The same problems existed when it came time to evaluate the various parameters. Standards don't exist. However, in this instance tradition does exist.

Tradition says that cruiser steering wheels will be vertical and attached to the main bulkhead of cruising power boats. Standup operation is traditionally considered to be the primary mode of operation. The seat is considered secondary as is seated operation. But these are "traditional" concepts, and contemporary small cruiser operators prefer to sit and therefore, order their cruisers with seats, which creates another problem. The wheel is positioned for standup operation. If the operator generally sits behind the wheel, human engineering seat/wheel relationships may suffer.

3.3.6.5.1 Visibility

The two cruisers were evaluated from the standpoint of seated operator visibility using the technique described in 3.3.6.3.1, above. Results are shown below.

Boat #	Obscured Visibility Distance (Ft.)	Meets ABYC Standard
1	4868	No
2	Totally Obscured	No

Visibility over the cabin top of both boats was obviously bad.

In one case, the water was obscured to the small seated operator for almost a mile in front of the boat. In the other case the small, seated operator couldn't see the horizon at all over the cabin top.

Obviously, a problem exists with these two models and may exist with similar boats of this type. Research is needed in this area to define the overall problem, determine if some types of cabin cruisers have significantly better or worse visibility problems, and offer solutions to those problems found.

3.3.6.5.2 Standup Operation — As in the center console boats, standup operation is generally considered to be essential and in fact the wheel and controls are located so high that an operator seated behind the helm in a chair of normal height couldn't reach the controls or see over the bulkhead at all. Hench the control stations must be evaluated from the standing position. Steering wheel height was evaluated using the same criteria as was used in evaluating the wheel height of center console boats. The middle of the wheel had to be at least 30 inches from the floor. However, in this case it could be mounted quite high. In fact, so high that a short person may not be able to see over it. Therefore, the maximum height of the top of the wheel was arbitrarily positioned at the eye height of the 5th percentile female operator which turns out to be 55 inches.

The minimum horizonal distance between the wheel and the seat was specified as 12 inches for center console boats. One major boat manufacturer uses 9 inches as their minimum dimension. Since 95th percentile males are thicker than 9 inches and clothes of course add to this dimension, 12 inches was used as the minimum acceptable dimension for cruisers also.

Wheel height and wheel to seat distance are shown below.

Boat #	Wheel Ht. — Middle of Wheel > 30"	Wheel Ht. — Top of Wheel < 55"	Standing Wheel Ht. OK	Wheel to Seat Dist. > 12"
1	Yes	Yes	Yes	No
2	Yes	Yes	Yes	No

The wheel height was adequate for the standing operator in both boats; however, there wasn't enough room to stand behind the wheel because the seat was mounted too close in both instances (4 inch separation).

Both seats folded down for standup operation, but required a lengthly disassembly and reassembly procedure.

Therefore, standup operation was impossible in both boats with the seat in position. If the seats were folded down, and were wanted for use during a cruise, the operator would have to leave the helm for some period of time while the seat was erected. This time could vary from 30 seconds to well over a minute. Obviously, the operator would be inattentive during this period of time and a collision could result.

3.3.6.5.3 Sit Down Operation — It was mentioned above that the seats were more or less permanently mounted and there was insufficient room behind the wheel for the operator to stand. Therefore, it would seem that the designer intended that the boat be operated from the seated position. This tends to place more importance on the seated operation than in other types of cruisers where stand up operation is definitely the primary mode of operation.

The seat itself was compared to the acceptable range of seat cushion angles and back seat angles as described in figure 3-32 in section 3.3.6.3.2 with the following results.

Boat #	Seat Within Acceptable Range
1	No
2	No

The angular dimensions of both seats were out of the acceptable range in figure 3-32. In addition, one of the boats didn't have a foot rest although the seat was 29 inches off of the floor.

3.3.6.5.4 Seat To Wheel Relationships — The horizontal and vertical position of the wheel was compared to the criteria established for runabouts in one case because the control station was designed to those criteria; however, in the other case the wheel was vertical and would be forward of the operator's knees when he was operating the boat from the seated position.

The one applicable wheel configuration fit the runabout criteria quite well and is shown below:

Boat #	Horiz. SRP to Wheel Dist. 18 to 21"	Vert. SRP to Wheel Dist. 8 to 11"	Combined
1	Yes	Yes	Yes
2	N/A	N/A	N/A

3.3.6.5.5 Knee and Foot Room — Here as in 3.3.6.5.4 above, the two control stations differed. The first was designed so the operator's knees could pass under the wheel. In the second case, the wheel was mounted vertically in front of the seated operator's legs. The first could be evaluated as were the runabouts. In the second, the criteria must be whether or not there is room between the wheel and the SRP for the operator's legs. Results are below.

Boat #	>27" Horiz. Clearance	>27" Vert. Clearance	Adequate Clearance
1	Yes	Yes	Yes
2	No	N/A	No

Results showed that there was inadequate leg room for the seated operator in one of the two boats. This is interesting since there was inadequate standing room behind the wheel in both boats.

3.3.6.5.6 Conclusions — Cruisers — An overall look at the evaluations against the human engineering criteria appears below.

Boat #	Visibility Meets ABYC Standard	Wheel To Seat Horiz. Distance Adeq. Standing	Wheel Height Acceptable Stand Up	Seat Adequate	Seat/ Wheel Sit Down	Knee & Foot Clearance	Meets All Criteria
1	No	No	Yes	No	Yes	Yes	No
2	No	No	Yes	No	N/A	No	No

Only two boats were measured and this could hardly be termed as a reasonable sized sample to base any sort of design critisisms. However, the two boats measured were popular models presently being advertised and sold nationally and in fact, were measured on the dealer showroom floor.

Results showed that the height of the steering wheel was just right for standup operation; however, there was only 4 inches of space between the wheel and seat for the standing operator --- obviously not enough. Therefore, one had to sit to operate the boat, but the seats were not designed within acceptable critera, one boat didn't have nearly enough leg room, and the visibility from the seated position was exceptionally poor. One boat didn't include a foot rest even though the seat was 29 inches off the floor.

So, obviously there were serious human factors deficiencies within the control station area of the two cruisers that were measured.

3.3.6.6 Conclusions and Recommendations

It was mentioned that automobile, aircraft, and military vehicle control stations are designed to human engineering's standards. Boat control stations aren't. What effects could this have on collisions? Definite statements cannot be made at this point but we know that 90 % of the collisions were coded as being caused by operator failure. We also know from our VAST experiments that stressors including fatigue can cause the boat operator's performance to degrade. There is, therefore, the possibility that:

1. A poorly designed seat can cause fatigue.
2. A poorly placed steering wheel or control lever can cause fatigue.
3. Inadequate leg clearance or foot clearance is stressfull.
4. The combination of the above along with the other stressors that the boat operator must deal with could definitely degrade his performance.

The fact is that this evaluation has barely scratched the surface of the human engineering problem areas within the boat control station area. Much work needs to be done.

In the introduction to this section, we said that relationships of various components of the control station will be compared to human engineering data to determine if there is a problem which could affect the performance of a boat operator. Based on the foregoing evaluation, the answer to that question is yes.

3.3.7 Space Envelope Development

The four types of control stations obviously require four types of space envelopes due to the fact the operator/seat/control relationships are different in each case.

Since boat control stations traditionally vary so much, especially when compared to an automobile control station, or aircraft cockpit, specific envelope dimensions or characteristics cannot be specified.

Because of the fact that the boat operator has not been defined, that is, we have not as yet determined what segment of the population we want to design for, we cannot be specific about the dimensional characteristics of each of the four control station types. However, some conclusions can be made especially in the area of the creative processes in the development of the control station space envelope.

3.3.7.1 Small Boats - Controlled From Engine

The control station in this case is non-existant. The operator steers and controls the throttle and gear shift from the engine itself. In this case the engine and controls are located behind the operator. It is interesting to note that this is probably the only vehicle where the operator must reach behind him to operate the controls.

Since the concept of locating the controls violates all human engineering principles, it becomes difficult to discuss space envelope criteria from the human engineering viewpoint; however, some criteria are worthy of mention.

1. If there is a thwart or operators seat forward of the transom, sufficient room should be allowed for the outboard to swing up without having the power head hit the operator in the back.

2. The seat or thwart should be located far enough forward that the steering arm on the engine clears the operators back when he is steering.

3. There should be sufficient foot room forward of the thwart or seat for the operator to turn partially sideways so that he may reach the engine control handle.

4. There should be sufficient room forward and aft of the thwart to adequately service and start the engine.

3.3.7.2 Runabouts, Bowriders, Bassboats, and Certain Flying Bridges

This type of space envelope is relatively easy to define since it is so similar to the automotive space envelope. The specific dimensions may be established once the operator population and maximum trim angle are known.

The definition process should proceed as follows:

1. Establish a minimum eye height that would take the form of an imaginary straight line that passed through the control station, over the highest obstacle forward, which would normally be the bow, and would terminate at a point on the water some specified distance from the bow. This would be done with the boat pitched up at some specified bow high attitude. The control station envelope would then have to be designed with all seated eye heights above the imaginary line.

2. Once the eye height is known the seat may be placed based on seated eye heights of the operator population.

3. The seat to floor distance would then be determined and based on that, the seat to bulkhead distance could be specified.

4. The wheel would be positioned based on the seat position.

5. The other controls and displays would be positioned based on seat position, eye envelope, and wheel position.

6. Windshields, windshield wipers, cabin tops, pillars, windshield frames, etc. would be positioned in relationship to the seat and eye envelope.

A design standard for this type of control station would be within the present state of the art, and based on the results of section 3.3.6 of this document, it appears to be warranted. The only missing information is a population definition and an agreement on what maximum trim angle to use.

3.3.7.3 Center Console Boats

The space envelope of center console boats is similar to that of cruisers with two major differences:

1. The seats in center console boats are generally lower.
2. The control console generally resembles a runabout console except that it is raised so that the standing operator can easily reach the wheel without stooping.

The space envelopes of center console boats resemble cruisers from the standpoint that the operator may drive the boat from the standing or sitting position. Presently, many of these boats are designed with helmsman's seats that double as fishing chairs when turned around to face aft. Hence they are positioned so low that the operator cannot see over the bow when seated and facing forward. Our position is that if a seat is permanently positioned behind the control console the helmsman should be able to see over the bow and all human engineering standards should apply.

The space envelope development process would proceed as follows:

1. Establish a minimum eye height that would take the form of an imaginary straight line that passed through the control station, over the highest obstacle forward, which would normally be the bow and would terminate at a point on the water some specified distance from the bow. This would be done with the boat pitched up at a specified bow high attitude. The control station envelope would have to be designed with all standing and seated eye heights above the imaginary line.

2. Once the eye height is known the seat may be positioned based on the seated eye heights of the operator population.

3. The floor is established.

4. The wheel is positioned in relation to the standing operator.

5. The seat is slid parallel to the eye height line until the horizonal SRP to wheel distance is within the acceptable range.

6. The vertical SRP to wheel distance is checked and the seat is moved to within the acceptable range. The seated eye heights are checked to make sure they are still above the eye height line.

7. The seat is moved aft enough to provide specified wheel to seat clearances for the standing operator. The distance it was moved aft becomes the distance that the seat must be able to slide.

8. Other controls are positioned within the reach envelope of both the standing and the seated operator.

9. Displays are positioned within the visual access area of both seated and standing operators.

10. Windshield, windshield frames and wipers, cabin tops, pillars, etc. are positioned in relationship to both the standing and seated eye envelopes. Neither should be compromised. The trick here is to get the standing and seated eye envelopes as close together as possible.

3.3.7.4 Cruisers

The space envelope development process of a cruiser is quite similar to that of the center console boat except that the steering wheel is usually mounted on the main bulkhead which is at a fixed position on the boat. Therefore, it is used as the basic reference plane in the control station design.

The development process would be as follows:

1. Establish the minimum eye height as in 3.3.7.3 above.
2. Establish the floor height in relation to the standing operator eye height.
3. Position the wheel within the acceptable range for the standing operator.
4. Position the seat behind the wheel so that the horizonal SRP to wheel distance is within the acceptable range.
5. Move the seat vertically until the seated eye heights are above the eye height line.
6. Check to make sure the vertical SRP to wheel dimension is within the acceptable range. Adjust 3, 4, and 5 until all dimensions are within the acceptable ranges.
7. Move the seat aft enough to provide specified wheel to seat clearances for the standing operator. The distance it was moved aft becomes the distance that the seat must slide.
8. Other controls and displays are positioned in accordance with steps 8, 9, and 10 of 3.3.7.3, above.

3.3.7.5 Conclusions

It is definitely possible to develop control station design guidelines or standards to be used by naval architects and boat builders.

The guidelines could take various forms that could range from a written "cookbook" to a set of drawings on Mylar at various scales. In the latter case, the designer could use the appropriate drawing either as an overlay to check his design or he could place the drawing under his design and use it to trace from.

Before guidelines can be developed, that portion of the population that is to be excluded must be defined. Anthropometric data for the remaining population should then be used to determine the range of overall heights, standing eye heights, sitting eye heights, leg clearances, reach distances, etc. that will be used to develop the specific dimensional characteristics of the space envelopes.

Also, a system of defining boat trim parameters must be developed. Using "average" or normal boat trim angles probably won't work since that says that half of the measured trim angles were higher than that number in which case the operator whose eye was located along the minimum eye height line couldn't see the water at the specified spot in approximately one half of the cases.

Wyle measured trim angles of 270 pleasure boats. Possibly this data could be used as the basis for developing the maximum trim angle based on the exclusion of a certain percentage of extremely high trim angles. The resultant maximum trim angle would include that angle found in all cases except the extreme hump angles that sometimes occur.

3.4 BOAT CHARACTERISTICS

3.4.1 Stopping Distances

3.4.1.1 Introduction

The distance required to stop a boat can be important to the collision avoidance problem. We can assume that a boat operator has two options open to him when he is confronted with a collision situation ahead of him. He can stop the boat or he can turn the boat to change his course to reduce the chances of collision. For the purposes of this discussion we will assume that only the first option is open to the boat driver. He has to stop to avoid the collision.

The question now arises how far does a boat travel after the throttles have been reduced and the shift levers have been pulled back to neutral or reverse. One can hypothesize at length about weight of boat, speed of boat, the resulting momentum, hull shapes, wetted areas, drag coefficients, etc. Wyle chose to test a group of boats of all sizes and shapes in an actual panic stopping situation. The results of the study are included as Appendix III-B are summarized below.

3.4.1.2 The Wyle Study

Eight boats, loaded as they would normally be for cruising, were piloted through a test course by their owners. In addition, Wyle personnel ran three USCG test boats through the same course. Each driver held a straight course at each of three predetermined throttle settings as he approached a set of buoys. He pulled back on the throttle and shift lever just as he passed the buoys and his stopping distance was measured from those buoys.

All boats could be stopped in about 230 feet after travelling at full throttle. The heavier boats were capable of being stopped in about 150 feet. The faster, lighter boats took longer to stop. It appeared that the time that the hull stayed on plane was the significant factor on the distance travelled after cutting the throttle.

Lighter boats in the 25 to 40 mph range stay on plane longer and travel the longest distance. However, heavier boats travel further in the displacement mode.

In summary, heavy boats stop faster than light, faster boats.

3.4.1.3 Human Factor Considerations

Based on the results of the above study, one could say that if a boat driver could see an object in the water at a distance greater than 250 feet (20 feet is added for reaction time and control manipulation time) the chances are that a boat could stop in time to avoid a collision with the object.

At what distance can the head of a fallen water skier be seen? Or at what distance can a log floating in the water be seen?

Miller (Reference 2, Chapter 9) states that the distance from which an object can be seen is a function of the visual angle for which the object subtends on the eye. He references a formula whereby one may calculate the distance at which various sized objects may be seen against a diffused background (water).

Using his formula, we find that a swimmer with his head sticking 10 inches out of the water would or could be seen with 97 percent probability from a distance of 238 feet. Whereas a 4 inch by 6 inch log with 4 inches of vertical visibility would have to be viewed from closer than 95 feet to assure the same probability of detection. It must be noted that these calculations are for ideal visibility and assume 20/20 vision of operator.

If we consider that the operator has no other option but to continue in a straight line and throttle back to avoid a collision with an object ahead of him the size of a human head or smaller, there will be some cases where the object will be run over before the boat can be stopped.

3.4.1.4 Further Research

The Wyle study referenced in 3.4.1.2 above was designed to identify whether a potential problem existed. The operators of the boats in the study did not put their boats into reverse and perform a "panic" stop as one would probably do if there were a person in the water

ahead of him and couldn't maneuver out of the way. Therefore, it is reasonable to expect that each operator could have stopped his boat in a shorter distance than he actually did.

However, the stopping distances may have been underestimated since the operator knew when he was to stop and probably anticipated (i.e., started his response before passing the buoys). Furthermore, the operator was prepared to stop. In a panic stop the stimulus is unexpected - this can make a large difference in reaction time.

Further research is necessary in this area of collision avoidance. Actual panic straight line stopping distances should be identified along with certain collision avoidance maneuvering techniques to determine the stopping distances of each technique.

Studies should be performed to determine what collision avoidance techniques untrained people actually use. Actual techniques used by untrained people should be compared to the optimum techniques to determine the probable differences in whether a collision could have actually been avoided.

Past collisions should be reviewed to determine how many collisions might have been avoided if the operator would have used a suggested avoidance technique. Educational methods should be considered and a cost/benefit analysis performed. The results will serve as a guide to use in evaluating the size of the problem and the cost of a possible solution.

3.4.2 Turn Radii Versus Speed

3.4.2.1 Introduction

Closely related to the stopping distance problem is the problem of a boat's turning radius. In 3.4.1, the assumption was made that a boat driver would elect to remain on the same course and stop the boat by pulling back on the throttle and shift levers after seeing an object ahead that he would hit. The question now arises: What would happen if that driver elected to turn the boat in an effort to maneuver out of the way of the object that he was about to hit? How far along its original path would the boat travel before it physically moved out of the path and, therefore, would no longer collide with the object originally ahead of it?

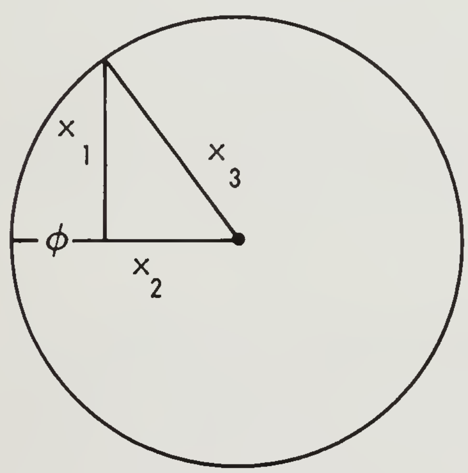
Would this be a lessor or greater distance that it would take to stop? And would the combination of turning and pulling back on the throttle change the characteristics of the maneuver?

3.4.2.2 Background

Turning radii were measured on eight (8) boats. The boats, piloted by their owners, were run through a test course to determine their turning diameters at various speeds. The study is included in Appendix III-B.

Since the referenced study was somewhat limited in that it gives us turning diameter measurements at 90° and 180°. It doesn't give us a measurement for a distance along the boat's original path at which point an object in the water would not be run over.

The distance in question could be derived by a formula which would calculate the length of a chord as shown in the illustration below:



where: x_1 = collision avoidance distance

ϕ = half of the boat's beam

$x_2 = x_3 - \phi$

x_3 = turning radius

$$x_1^2 = x_3^2 - x_2^2$$

$$x_1 = \sqrt{2R\phi - \phi^2}$$

However, this distance doesn't include any factor for the boat slipping sideways through the water due to centrifugal force, or for the addition to the half beam due to the fact that the boat is steered by the stern.

For that reason aerial movies of boats turning were studied to determine the actual distance along the original trajectory between the point of turn input and the point at which the path of the outside transom corner crossed the trajectory.

The two studies are treated separately then compared below.

3.4.2.3 Turn Radii Study

When we talk of a boat's turning radius we are introducing an error since the path of the boat actually approximates a decreasing spiral with the "radius" becoming smaller as the boat progressed through the turn. The "radius" was measured at 90° and at 180° from the original path. For the purposes of this discussion, only the data from the 90° measurement will be used since it is always the largest radius.

In order to specify some minimum collision avoidance distance based on the turn radii study, some radius must be used that would represent the maximum radius that the majority of the population of boats would be able to negotiate. Realizing the fact that the study (Reference Appendix III-I) was very limited in both scope, measuring accuracy, and number of boats used, the maximum radius measured will be used in order that the results may be considered to be conservative. Turn radii of the eight boats at three speeds each were plotted and are presented in Figure 3-37.

When the maximum radius of 150 feet is applied to the formula described in 3.4.2.2 and a half beam of four feet is used, the collision avoidance distance becomes 32 feet. Therefore, we could say that if we don't consider the side slip of the boat or the fact that it steers from the stern, almost any small boat can be steered out of its original path in 30 to 35 feet.

The question now is, how much distance is added to the 30 to 35 feet due to side slip and steerage by the stern?

Fifteen (15) small boats were photographed from the air as they were put into hard turns. The movie film was analyzed to determine the distance along the centerline of the boats' original trajectory that the outside transom corner cleared. Figure 3-38 is a tracing of a photographically reduced example of the data as taken from the film. Since the boat length was known, the distance could be scaled from that.

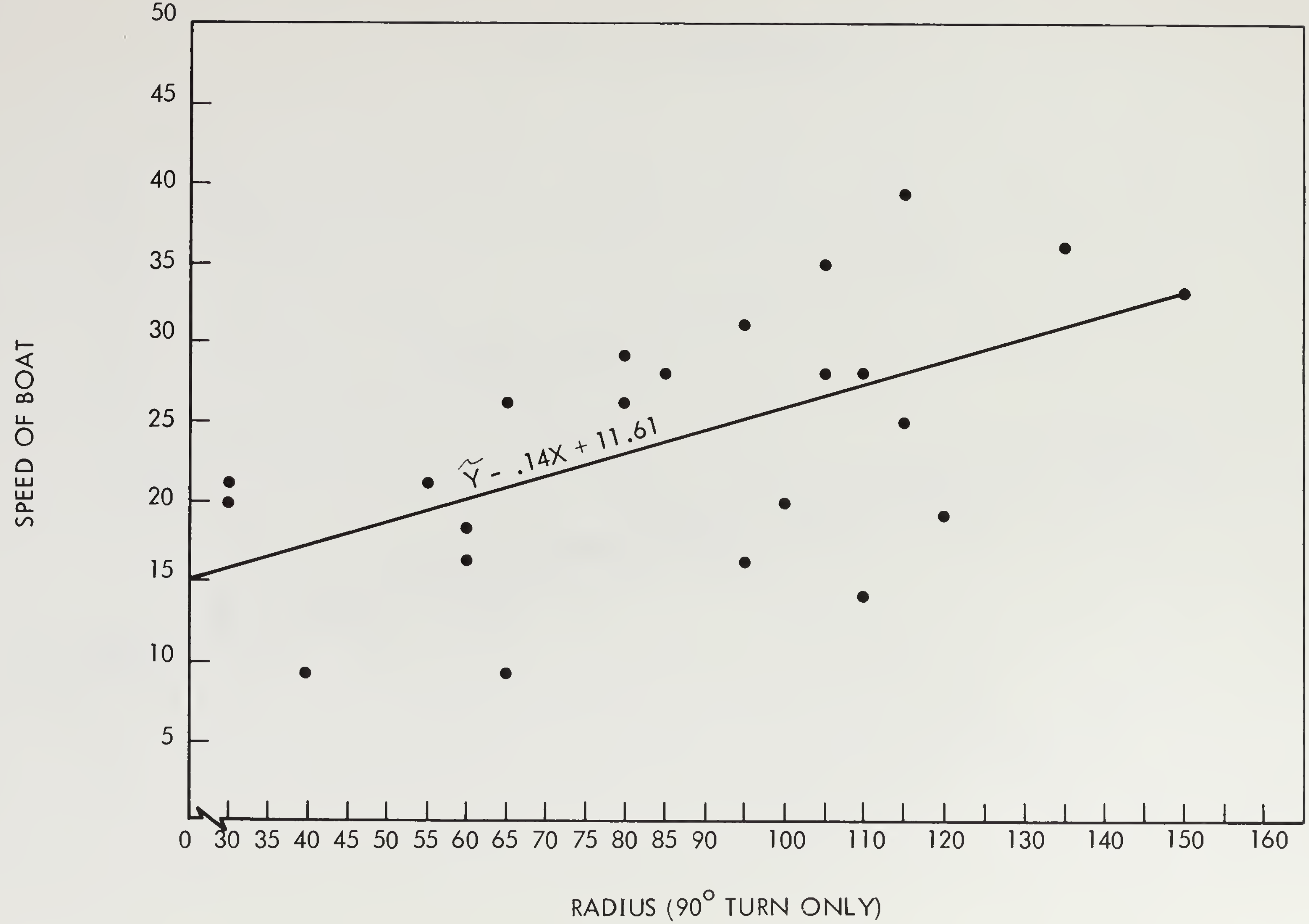


Figure 3-37. Boat Speed vs. Turn Radius

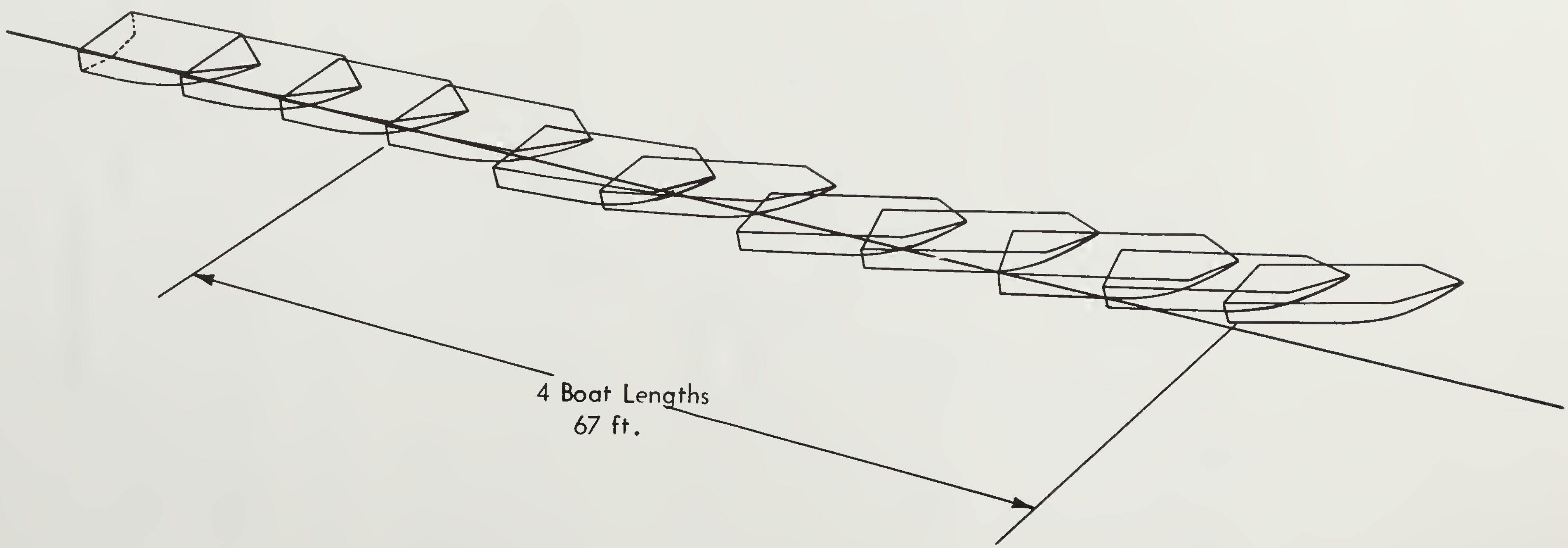


Figure 3-38. Boat Path Into Turn

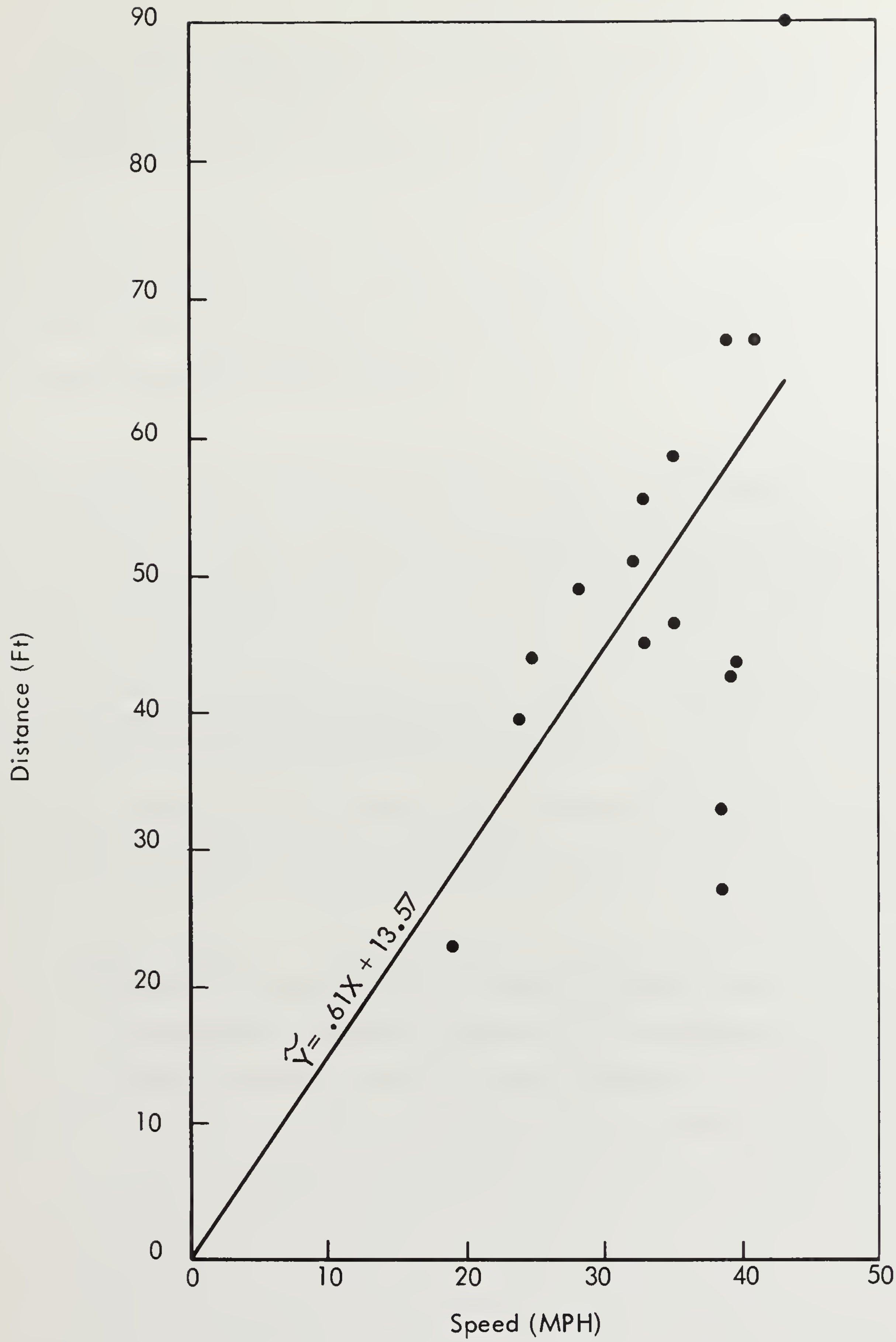


Figure 3-39. Collision Avoidance - Distance vs. Speed

The fifteen (15) data points were plotted on a distance versus speed graph, Figure 3-39. A regression analysis was used to find the best fit curve for these data points. It appears from this limited data that all boats but one were able to clear their original trajectory within 70 feet and all were able to clear in 90 feet.

When comparing the two studies it is interesting to note that the distance tripled when slip and stern steering were introduced. However the greatest distance recorded was still quite a bit less than the distance required for stopping by cutting the throttle and steering along the original path.

More data is needed in this area of the collision avoidance problem. Studies should be run with different types of boats to determine the optimum collision avoidance maneuver. Panic stopping techniques discussed in 3.4.1 along with turning maneuvers should be investigated.

As discussed in 3.4.1, actual collision avoidance techniques used by untrained boaters should be studied, and compared to optimum techniques to determine the probable differences in whether a collision could actually be avoided. Past collisions should be reviewed to determine how many collisions might have been avoided if the operator could have used a suggested avoidance technique.

If it is found that optimum collision avoidance techniques could reduce the occurrence of collisions, methods for education could be developed to teach boaters the proper collision avoidance techniques. Cost/benefit analysis could help in evaluating the size of the problem and effectiveness of the solution method.

3.5 EDUCATION

Many of the causes of collisions are "education based," meaning that the collision might not have happened if one or both of the operators involved had had more boating safety education. For example, in a recent survey of nighttime collision victims, over 80 percent of the factors that the operators thought were involved could be mitigated by educational programs. When these operators were asked what areas they thought the Coast Guard should investigate, the most popular responses by far were licensing and education. Both of these areas involve making the average boater more knowledgeable.

What are some of these causes where education could play a role? Inattention, carelessness, speeding, overloading, misinterpretation or no knowledge of "rules of the road," inexperience, running at hump speed (bow up), misleading or improper lights, not turning on lights, alcohol use, and not being aware of water and weather conditions are all causes and contributors to collisions that could be mitigated by educational programs. The problem is to identify these areas and their related safety concepts. Once it is known what we want the boater to learn, then a program can be outlined to teach it to him.

As examples, we will work through six of these problem area, identifying the safety concept and ways to get the message across to the boating public.

> Problem No. 1 - Maneuvering errors include the failure to turn to the right in a head-on collision situation and the failure to keep to the right in a channel, especially at an intersection. When boating operators were interviewed, they indicated a complete ignorance of the rules of the road in these areas.
>
> The concept here appears to be to know general rules of the waterways and, in particular, traffic pattern rules. These rules are very similar to automobile rules of the road with the exception of the lack of definition of lanes and "roadways" on the water. One approach to teaching these concepts might be to relate to the operators probable automobile experience and to alert him to the fact that there are other boaters out on the water. The automobile driver stays in his lane, even at night,

even if he hasn't seen another car for a long time, because he realizes the dangers of going against the rules of the road.

Problem No. 2 - Navigation errors found in the 1974 summer study caused collisions with rocks and, in one case, a navigational aid. Operators indicated unfamiliarity with the areas and little understanding of the inherent dangers. Education in terms of the awareness of inherent dangers and the importance of following safe charted courses seems to be the most appropriate way to reduce these types of collisions.

The concept in this case is that navigation charts and aids are there for a reason. There are many hidden dangers under the water. One educational approach might be to visually present a clear water surface (in person, on film, or in a model) and then show the hidden dangers underneath (tree stumps, sand bars, shallow depth) and some of the results of ignoring these hazards. The problem is that the boater is unaware of these dangers until it is too late. He needs some perceptual confirmation of the hazards and the value of the safe charted courses and navigation aids. Then he will be motivated to learn to use these safe boating aids.

Problem No. 3 - Education in terms of a learned respect for the effects of weather conditions on small boats and the characteristics of weather changes on waterbodies is felt to be the best way to reduce the type of collisions classified as "disregard for weather/water conditions."

The safety concept here is to know the limitations of your craft (this applies to more than just weather). This is one instance where the transfer of knowledge from driving an automobile may be dangerous. In an automobile, the operator is protected from the weather and his vehicle is fairly safe even in rough weather. In small boats, it does not take much foul weather to make operation of the vehicle very difficult. One educational approach might be to ask students in safety courses to try to balance a johnboat in moderate waves (under supervision) to get a feel for what weather (wind in this case) can do to make boating difficult. There are many aspects to the weather. Heat, glare, waves, precipitation, etc., are all safety concerns for boating. The

operator should check his forecast for all of these factors and plan his activities and take provisions accordingly.

Problem No. 4 - Failure to have lights or turn them on is a common cause of nighttime collisions as well as failure to interpret lights properly when they are seen. Boaters could be better educated as to the reasons for the lights and what they mean.

The concept to be taught is to have the proper lights on board in nighttime operation and to use them. The boating operators have some legitimate concerns about the glare problems with some of the lights and other matters. However, these problems can be handled with a little effort. The boater should know the reasoning behind the lights and the colors. This will motivate him to use them. Other problems include dark adaptation problems and confusing lighting arrangements. Demonstrations could be arranged to show how much more one can see in general with a spotlight off, for example, or how errors could be induced by illegal lighting arrangements or no lights.

Problem No. 5 - Panic, or the act of the operator making the wrong decision in an emergency situation, is a broad category that is felt to be primarily education based. In this case, classroom education can go just so far. Some amount of practical experience is necessary to complete the educational base needed to reduce the number of collisions from "panic."

The concept is to react rationally and appropriately to an emergency. While everyone will nod his head in agreement with attempting to get people to behave this way, no one will behave this way merely by being told to. Behavior in panic situations is usually on the level of reactions to stimuli. Water on the legs makes the passenger stand up (making the boat unstable and capsizing it or causing the passenger to fall overboard). The first reaction for a lot of people in a collision avoidance situation is to turn the wheel (usually in the same direction as the other boat) rather than to pull back on the throttle. These types of responses must be taught in the real situation (or a good simulation of it). The boater will often not have the time, inclination, nor the emotional stability to think about what he should do. The proper reactions should be

quick and well-rehearsed in the emergency situation. One could start a fire on a test boat and have boating safety students put it out. Other demonstrations could be arranged as well.

Problem No. 6 - Many accidents happen as a result of the boater not being aware of his own and his boat's limitations. He may not realize how severely his vision is limited by a raised bow or how little alcohol it takes to influence his boating abilities. Education seems to be an effective means of getting these messages across.

The concept essentially is to define the limitations of safe boating. How many cases of "negligence" or "horsing around" were merely cases of overestimation of the operator's abilities or his boat's capabilities. Boating is a fun and social activity. It is not thought of as seriously as driving a car or flying an airplane by the typical operator. Rather, it is often thought of as a vehicle where one can "let off some steam." This attitude is tolerable as long as one stays within the limits of safe operation. Boaters could be educated as to the ways various stressors can affect them and what these effects mean in terms of safe boating. Safe stopping distances and turning radii and other performance characteristics of boats could be outlined. Here, again, some real-world demonstrations might be in order. The television commercials dealing with sunglasses and glare are quite effective in illustrating the problem, the danger if it is ignored, and the proper solution. One can learn by watching others. They do much more than words could do. Similar exhibitions could be designed for heat, noise, vibration, lights, bow angles, and other boating safety guidelines.

Problem No. 7 - Carelessness and inattentiveness constitute one of the primary reasons for boating accidents. How can we get people to be more attentive? Two possible approaches are: (a) change the equipment, or (b) change the operator.

Boating equipment, especially controls, can be changed in such a way as to require greater operator attention. For example, a throttle which requires constant pressure (such as the automobile foot throttle) would greatly increase the chances that the

operator remain at his station and is oriented in the proper direction. Of course, such control devices can be defeated (e.g., by placing a heavy object on the foot throttle); therefore, this approach alone will probably not be sufficient. The operator's attitude and behavior must also be changed.

Attitude and behavior change can be accomplished through education, mass communication, regulation and incentive. The importance of attitude and behavior change can be recognized by comparing people's conduct in driving automobiles to their behavior in piloting a boat. Rarely does the automobile driver look away from the road for extended periods of time or have one hand on the wheel and a can of beer in the other. Attitude and behavior change is not only important, but also feasible. Witness, for example, the recent reduction in speed (and consequently fatalities) on highways. Other examples of mass changes in attitude abound. Consider, for example, the changes in attitudes and behavior toward members of minority groups in the United States.

This is not to say that attitude and behavior change is easy and does not pose special problems. In attempting to manipulate attitudes and behavior, one must guard against unwarranted or unnecessary invasions of privacy and restrictions of the individual's freedom. Nevertheless, some measure of attitude and behavior change is probably essential to effect any large scale reducation in boating accidents.

These are but six of the causes that could be handled through educational programs. There are others and there certainly are other educational techniques available. The particular technique chosen, whether it is television commercials or large fines for violations, will depend upon the desired effect and the audience that one is attempting to reach.

Several points are in need of investigation from the standpoint of educational psychology. The preceding list is a list of subjects that the boater should know. Knowing the goal of an educational program is only half the battle of achieving it. The goal in this case is to have

boaters that don't make these mistakes or at least don't make them as often. The second half of the battle is to design the program to achieve the goal. One of the inescapable arguments from the list above is that boaters need real-world experience with the problems described. Experience is the best teacher. Learning how to behave in a panic situation is a good example. No matter how much one practices the proper reactions, unless they are practised under stress, it will do little good. When the stressful situation occurs, behaviors are displayed that are seldom thought about, but are just reactions. The proper reactions, to be trained properly, should be practiced <u>in the stressful situation</u>.

4.0 SUMMARY - TASK III

Each section, i.e., operator stressors - environmental and equipment based, boat characteristics, and education, is summarized separately below.

4.1 OPERATOR STRESSORS - ENVIRONMENTAL

- An experiment was developed to measure performance degredation due to environmental stressors. Results showed that the combined daytime stressors (heat, sun, glare, vibration, exposure duration, etc.) did degrate the operator's performance. Not only were reaction times longer but the operators missed ten times as many signals when they were fatigued.

- Wyle intends to repeat the stressor experiment during the summer of 1975 using alcohol as the stressor. Additional laboratory and field experiments will attempt to isolate and determine the relative effect of individual stressors.

4.2 OPERATOR STRESSORS - EQUIPMENT ORIENTED

- Visibility - visibility distances of 270 underway boats were measured:
  - 10 percent of the operators couldn't see the water in front of them.

- Visibility problems that were found to be severe included:
  - Glare
  - Windshield cleaning methodology
  - Tinted windshields
  - Objects forward of operators
  - People forward of operators
  - The sailboat visibility problem area.

- Control forces - steering wheel

  Measured wheel forces exceeded strength capabilities of a portion of the boat user population.

- Control forces - shift and throttle levers

  Measured lever forces exceeded strength capabilities of a portion of the boat user population.

- Noise

  211 sound level measurements made from the operators position of boats under power were analyzed. A significant number of the data points fell within the range of sound levels that mask speech communication, cause temporary and permanent hearing losses, and may cause other physiological problems.

  Most startling were the results of the referenced wind noise experiments. Sound levels from wind alone measured over 100 dBA inside the human ear at 40 MPH.

- Shock and Vibration

  Vibration was measured in the "normal" boating environment. Frequencies were found to fall within the range of resonance of the head. Amplitudes fell within the "unpleasant" range.

- Control station design

  Control stations of 12 runabouts, three center console boats, and two cruisers were measured and evaluated against known human engineering standards. None of the boats met the standards. Some serious problems were defined.

4.3 BOAT CHARACTERISTICS

- Stopping distance and turning radii

  Both were studied to determine collision avoidance distances.

4.4 EDUCATION

In order to gain maximum benefits from educational programs, the instructional methods and demonstrations should incorporate real world experiences.

4.5 FURTHER RESEARCH

In most cases problems were identified and further research was indicated. The next step for many of the problem areas seems to be to:

1. Determine how to reduce or eliminate the problem.
2. Determine the cost of reducing or eliminating the problem.
3. Estimate how many collisions could be avoided.
4. Perform cost effectiveness studies.

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APPENDIX I-A

ACCIDENT INVESTIGATION FORMS

ACCIDENT NO. ____________________

INFORMATION REPORTED TO WYLE BY G-BBC

TYPE ACCIDENT: ____________________ DATE OF ACCIDENT: ________________ DATE RECEIVED REPORT: __________

USCG UNIT MAKING REPORT: ____

DESCRIPTION OF ACCIDENT: ________________________ NO. INJURIES/FATALITIES: ____________________

DESCRIPTION OF BOAT: (Include Registeration or HIN) ____

BOAT OWNER: (Include name, address, phone, etc.) ____

____

TENTATIVE BOAT AVAILABILITY: ____

INDIVIDUAL RESPONSIBLE FOR BOAT: ____

COMMENTS: ____

____

____

SCREENING BY WYLE

ACCIDENT ACCEPTED FOR INVESTIGATION? __________

INDIVIDUAL(S) CONTACTED: (with date) ____

____

WHO REPORTED ACCIDENT? ____

TO WHOM WAS ACCIDENT REPORTED? ____

IS OWNER/OPERATOR/WITNESS AVAILABLE? __________ IS BOAT AVAILABLE WITH OWNER'S PERMISSION TO USE? __________

IS WATER AVAILABLE? __________ DISTANCE FROM BOAT? __________ TRANSPORTATION? ____________________

MARINA FACILITIES AVAILABLE FOR LIFTING HEAVY BOAT? __________ DESCRIPTION OF BOAT: ____________________

MATERIAL: ________________ HULL FORM: ________________ AGE: ________________

BOAT REGISTERATION NO. OR HIN: ____

COMMENTS: ____

____

____

CONTACT REPORT

Contact Report Of: ______________________ Telephone ☐ Visit ☐

Date Of Contact: ______________________ Follow Up Date: ______________

Agency Or Company and Address	
Phone	
Person(s) Contacted and Title	
Purpose	
Discussion	
Action.	
Copies To:	

549 Rev.

COLLISION SUMMARY SHEET

Wyle No.	Accident Date	Location	Collision Type

Deaths ______________ Injuries ______________ Property Damage ______________

Collision Details ____

Coast Guard Unit Making Report ____

Boat Type	Length	Accident Type	Seriousness Code	Accident Date	Wyle Investigation Date	Wyle Investigation No.	CG Accident No.

INVESTIGATION DATA FORM

BOAT TYPE	HULL TYPE	MATERIAL
☐ John Boat	☐ Flatbottom	☐ Aluminum-Riveted
☐ Bass Boat	☐ Semi-V $< 18^{\circ}$ Deadrise	☐ Aluminum-Welded
☐ Open Fishing Boat (other than above)	☐ Deep-V $> 18^{\circ}$ Deadrise	☐ Fiberglass-Single Skin
☐ Runabout - w/forward deck	☐ Hard Chines	☐ Fiberglass-Sandwich
☐ Runabout - bow rider	☐ Round Chines	☐ Wood-Carvel Planked
☐ Cabin Cruiser	☐ Cathedral	☐ Wood-Strip Planked
☐ Sailboat	☐ Tri-Hull	☐ Wood-Lapstroke
☐ Other ______	☐ Other ______	☐ Plywood-Sheet
		☐ Plywood-Molded

☐ Manufactured ☐ Kit Built ☐ Homemade ☐ Other ______

Comments: ______

BOAT SPECIFICATIONS

Mfgr: ______ Model: ______ Length Overall: ______

H.I.N.: ______ Serial No: ______ State Reg. No.: ______

Stability Warning Label: ☐ Yes ☐ No Min. Frbrd: ______ Where: ______ Max. Beam: ______ Where: ______

Transom Width (Gunwale): ______ Transom Width (Chine: ______ Transom Ht. at CL ______

Max. HP Capacity:) ______ Max. Persons Capacity: ______ Max. Weight Capacity: ______

PROPULSION

☐ Outboard(s) How Many: ______ HP each: ______, ______

☐ Clamped to Transom ☐ Bolted to Transom

☐ Inboard(s) How Many: ______ HP each: ______, ______

☐ I/O I/O Mfgr: ______ Model: ______

☐ Vee-Drive ☐ Gas ☐ Diesel How Many Rudders: ______

☐ Straight Drive Eng. Mfgr: ______ Model: ______

☐ Propeller Eng. Mfgr: ______ Model: ______

☐ Water Jet Jet Mfgr: ______ Model: ______

☐ Other, Explain: ______

CONTROLS

Outboard Boats

☐ Controlled from Engine

☐ Yes

☐ No (See Remote Steering)

☐ Forward/Neutral/Reverse

☐ Other, Explain ______

All Boats with Remote Steering

☐ Wheel ☐ Tiller

☐ Aft or - - - - - ☐ Forward of Amidships

☐ Port ☐ Center ☐ Starboard

Controls

☐ Manual ☐ Electric ☐ Hydraulic

☐ Same Lever for Throttle and Shift

☐ Throttle and Shift Have Different Levers

INTERVIEW REPORT FORM

Wyle No. ____________________ Date ____________________

USCG No. ____________________ Investigator ____________________

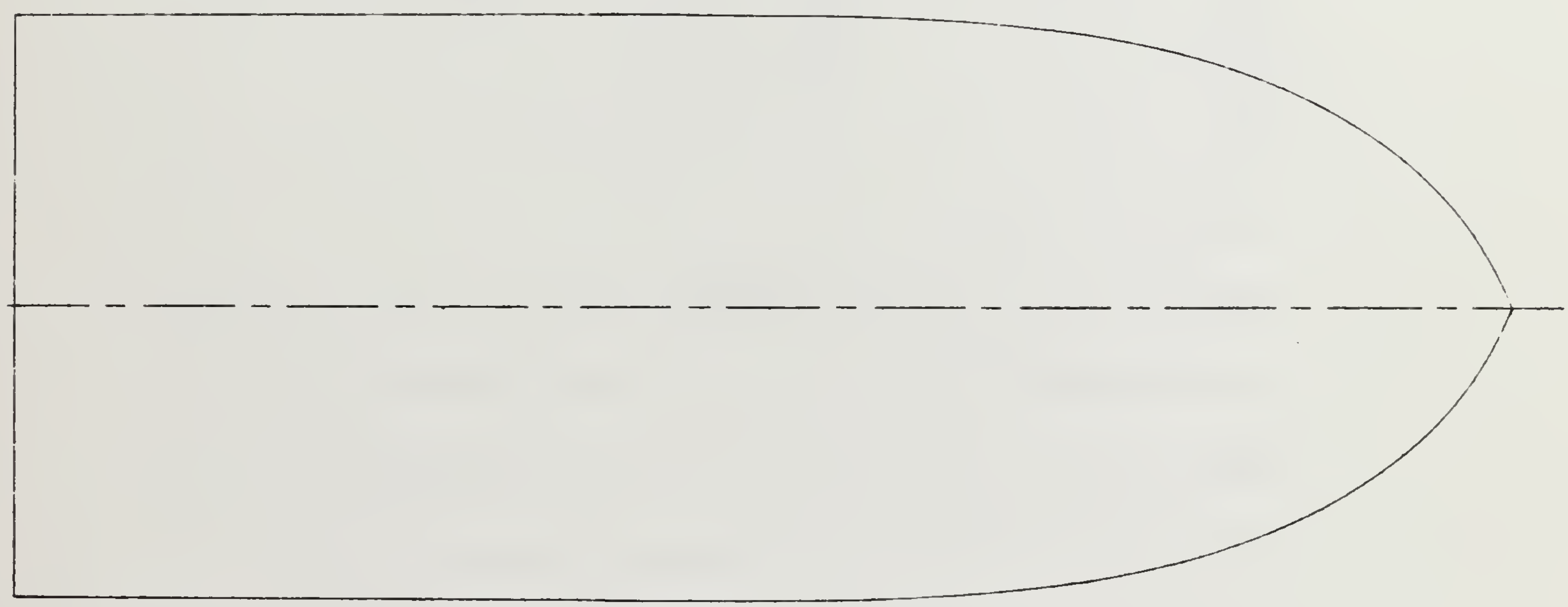
Respondant's connection with accident ____________________

1. OCCUPANT INFORMATION No. of Occupants ____________________

(A)

	Operator/ Passenger	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instruction	PFD's Worn	Other
1.								
2.								
3.								
4.								
5.								
6.								

(B) SKETCH OCCUPANT LOCATION — Also indicate static load distribution, i.e., all items weighing over 10 lb, battery, fuel tanks, (how full), ice chests, etc.



2. WEATHER — At time of departure

a) Air Temperature: ______________________

Wind: Force _________________ Direction ___________

Visibility: ____

General Description of Weather: ________________________

____

b) Any changes in weather from time of departure until time of accident:

____

____

3. WATER BODY CHARACTERISTICS — Just prior to accident

a) Type of water (check all that apply:

Open	_____	Lake	_____
Sheltered	_____	River	_____
Sea	_____	Tidal	_____
Fresh	_____		

b) Condition of water

Depth: _________________ Roughness (waves): ___________________

Current magnitude: _______________ Current direction: ___________

Tidal conditions: _______________________ Temperature: __________

Other traffic (describe): ______________________________________

____

____

____

4. PRE-ACCIDENT CONDITIONS

a) Describe boat trip before accident situation occurred. (Narrative description of purpose of trip; activities such as fishing, skiing, stopovers, weather and water conditions; also <u>times</u>.)

b) Sketch boat relative to shore and to other boats, structures, objects, and people in water. Show approximate distances, direction of wind and waves.

5. ACCIDENT DETAILS What time did it occur? ______________________

a) Was there anything unusual about the way the boat handled before or during the accident? For example, was there any difficulty maintaining steerage, trim, heel, speed or general stability?

No __________ Yes __________

b) If yes, describe, including possible explanations: ______________________

____

____

____

c) Describe sequence of events in accident situation. ______________________

____

____

____

____

____

____

____

____

____

____

____

____

d) Was any equipment moved, or did any equipment shift location just before or during the accident?

No ________ Yes ________

If yes, describe: ____

____

____

____

____

e) Was there water in the boat at the time of the accident?

No ________ Yes ________

If yes, approximately how much? ________________________________

When was it taken on? ____

What attempts were made to remove it? __________________________

____

____

____

f) The space below is provided for any additional information and comments you think might be useful in the analysis of this accident:

6. POST ACCIDENT DETAILS

a) Situation of boat: Describe:

Flooded ______________________________

Sunk ______________________________

Afloat upside down ______________________________

Other (describe) ______________________________

____

b) Damage to boat (describe if any): ______________________________

____

____

____

c) Injuries or deaths (describe if any): ______________________________

____

____

____

d) Describe rescue operations, if any: ______________________________

____

____

____

____

e) Describe boat recovery operations, if any: ______________________________

____

____

____

7. ADDITIONAL INFORMATION, IF APPLICABLE

a) Overall condition of boat before accident (describe any defects or damage and whether corrected):

____

____

____

b) Describe any modifications to boat: ______________________

____

____

____

c) Describe any previous accidents in which boat was involved: ____________

____

____

____

____

d) Indicate experience of boat operator and occupants on the subject body of water or type of body of water, and their experience with similar water, weather, and wind conditions:

____

____

____

____

____

____

____

APPENDIX III-A

RECREATIONAL BOAT OPERATOR STRESSORS: THE VISUAL ALERTNESS STRESSOR TEST (VAST)

RECREATIONAL BOAT OPERATOR STRESSORS: THE VISUAL ALERTNESS STRESSOR TEST (VAST)

ABSTRACT

The use of a secondary task to measure degradations in the performance of a primary task is well documented in the human performance literature. This research effort involved the design, construction, and development of the Visual Alertness Stressor Test (VAST) as a means of measuring the effects of stressors on a boat operator's performance. The VAST task required the subject to respond to particular patterns of lights displayed in a semi-circle around the cockpit of the boat while he maintained a specified course with the boat. The basic measures taken were the response time from pattern onset to control activation and the number of errors (both false responses and misses). A 2 x 2 factorial design was used where the factors were 1) the type of fatigue used between tests, and 2) the amount of fatigue before each test (rested versus fatigued). The results confirmed that the overall effect of "typical" exposure to the environmental stressors of boating was a doubling of the average reaction time to VAST stimuli, and a large increase in the number of missed signals. No measurable difference in the two types of fatigue was found. Future research efforts and applications of VAST are discussed.

1.0 INTRODUCTORY SUMMARY

The VAST experiment and research program grew out of a need by the Coast Guard to know about operator errors, and stressor effects in particular. Various avenues of research have shown that operator-related problems account for from 65 to 90 percent of the causes of boating accidents. How do these operator problems come about?

Many of them may be due to lack of boating experience or lack of education in safe boating. Other causes include poor operator attitudes (leading to inattentiveness, carelessness, reckless-ness. However, many of the causes may involve stressors either directly or indirectly. An operator may not see another boat because of glare from the sun (direct influence), or he may be slow to react to a dangerous situation because of alcohol (indirect influence). In either case, the stressor contributed to the accident.

The VAST apparatus consists of a seventeen foot runabout equipped with a semicircular light display driven by a mini computer. There are several devices and controls to be used and manipulated by the experimenter and subject (see Figure 1).

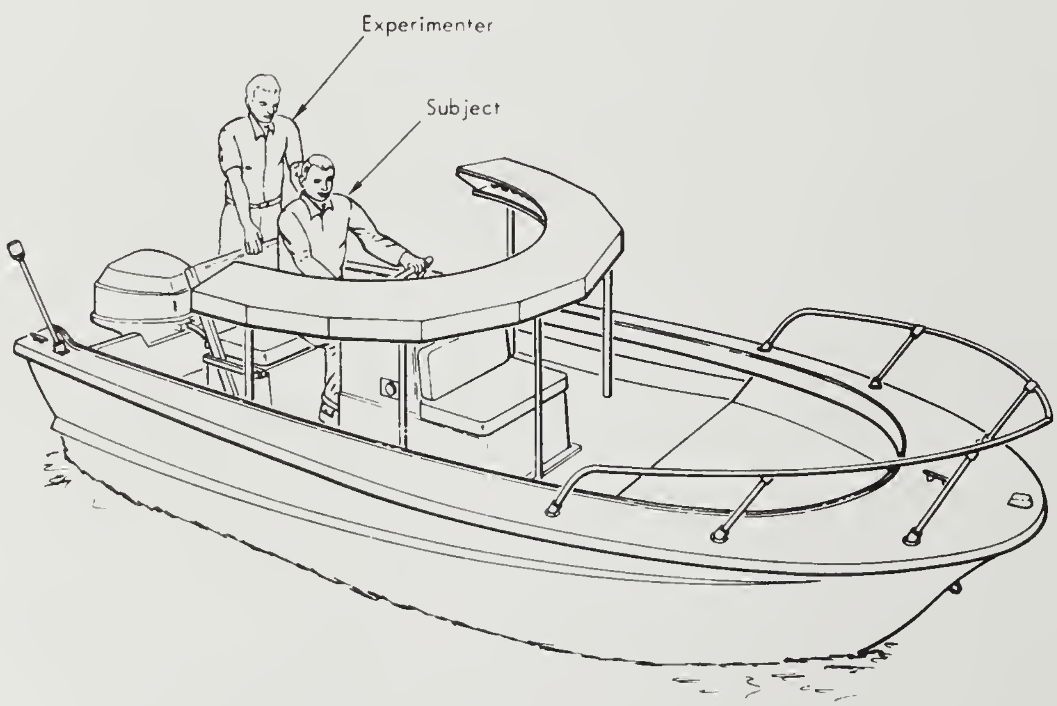


Figure 1. Experimental Apparatus - Visual Alertness Stressor Test (VAST)

The subject's task is to steer the course dictated by the experimenter and respond to particular light displays as they are presented. The performance measures taken were the number of significant deviations from course, the reaction times of the subjects, and the number of errors in the VAST task (both responses to inappropriate light patterns and "missed" patterns).

This initial VAST experiment involved a 2 x 2 factorial design. Two levels of fatigue were used and two types of fatigue. Subjects were tested in a "rested" condition and an "exposed" condition. Some subjects were exposed to the type of fatigue that might be associated with a "family boating outing" (mostly exposure to sun, heat, glare, and some light physical activity), other subjects went through some activities that might be associated with a "fisherman's outing" (including exposure plus drifting on the water and some added activities in a boat under power). The subjects were tested in the morning (rested) and after three hours of exposure to stressors according to one of the scenarios just described (fatigued).

The results showed a significant difference between the rested and fatigued performances, but no difference between the two types of fatigue. This means that the exposure to the combination of daytime stressors (heat, glare, vibration, noise, etc.) did cause a degradation in boating performance. However, the type of exposure (whether it was the more "mental" family scenario or the more "physical" fisherman scenario) did not seem to matter. The results also showed that the VAST apparatus and experimental paradigm are sensitve to the performance degradations induced by boating stressors, and that subjects could learn to perform such a task in a short time.

Since the results were so encouraging, future research is planned to investigate alcohol and other stressors in detail using VAST. This research may involve some laboratory applications to determine appropriate stressor levels to be used, and it may include modifications and improvements to the present VAST system to accommodate other stressors.

The next section (section 2.0) will present the background to the VAST study, and the experimental paradigm. Section 3.0 will discuss the VAST experiment and apparatus in detail. Section 4.0 discusses the data and results of the experiment. Section 5.0 contains the conclusions and recommendations based on this research, proposed modifications of VAST, and proposed future applications.

2.0 BACKGROUND

Past investigations have shown that up to 90 percent of the causes of boating accidents are people-related. The BAR summary statistics for 1973 show the people-related causes account for 89+ percent of the reasons for accidents. The 1974 collision summer report done at Wyle shows this fraction to be 90.5 percent, and the recent interview of nighttime collision victims generated a figure of 89.2 percent. Thus it appears that a large percentage of boating accidents are caused by operators or operator-related factors.

What causes these operator errors? Is it lack of education? Is it one of those poorly defined words such as carelessness, inattention, or negligence? Or is the cause more highly correlated with the presence of external influences which have become known as stressors? In truth, "the cause" is probably a combination of these things.

The idea of looking at stressors as potential causes is not new, and it is for this reason that the approach is promising. In automobile, air craft, and industry, stressors such as heat, glare, noise, vibration, weather, control forces, alcohol, etc., have been found to be significant determiners of human performance. This research forms a basis for investigating stressors in boating. Several questions then arise. Are stressor effects similar in boating to those in cars and planes? Are there new and different stressors in boating? Are there any stressors and stressor effects in boating at all? What is the best way to approach these problems in researching the area?

Obviously, there are stressors in boating. The boat operator is much more exposed than an automobile driver. The boat driver has no air conditioner to counteract heat, no muffler, fire wall, roof, or radio to overcome engine noise, no roof to help with wind, glare, and sun, no seat designed to counteract shock and vibration, no sophisticated cockpit design to aid in visibility and operation, and no injury prevention or crashproof design to the cockpit surround. Alcohol effects both the car and the boat operator, but, with all that he's exposed to, the boat operator may feel as though he needs a drink. In any case, there is greater potential for the effects of alcohol to be increased by combining with other stressors in boating.

Given the presence of stressors in boating, the issue becomes, do they have any effect on performance, and if so, how do we find out?

For several years, one fruitful approach to stressor effects has been to study divided attention tasks. These are tasks where, essentially, the subject is asked to do two or more things at once. The well-known children's game of patting oneself on the head while rubbing one's stomach is an example of such a task. In psychological experiments involving stressors, these tasks typically involve mental manipulations. The general paradigm is to ask the subject to perform at a specified level on one task (the "primary task") and to do as well as possible on another task (the "secondary task"). Variations from this paradigm are endless. One can introduce stressors, demand the same performance as always on the primary task, and look for a degradation of performance on the secondary task due to the presence of the stressors. The greater the degradation, the greater the influence of the stressors. Thus, performance on the secondary task could be used as a measure of stressor effects. Although there are other variations on this experimental paradigm, the one described above suits the purpose of investigating stressor effects. How can this technique be implemented?

To a boater the primary task is to operate the boat safely, keep it on course, and head for his destination. The problem is to come up with a secondary task. This is what the <u>V</u>isual <u>A</u>lertness <u>S</u>tressor <u>T</u>est (or, VAST) is. It is a secondary task to be performed on the boat. This experimental apparatus will be described in more detail in the next section. It will suffice here to say that VAST is a secondary task that will allow stressors to be introduced and provide performance measures such as reaction times and error rates.

Before leaving the realm of stressor research in general and the background for VAST, some discussion seems appropriate of what stressors are and what the term "stress" means. In terms of human performance, stress is not something the individual defines, but is a characteristic or set of specifications of the demands placed upon the individual by himself, the task, and the environment. This definition of stress makes it manipulable (an independent variable) and frees the definition from subjective impressions of what is stressful or what is challenging. It is clear from this definition that not all stress leads to performance decrements. Indeed,

boredom may be defined as the result of a stressless situation. Thus, optimal performance may be obtained at some intermediate level of stress (church pews may be hard - stressful - merely to keep one awake and attentive). In the boating accident situation, one is concerned with several aspects of stress: principally task overload (too many boats or too tough boating conditions to operate safely) and environmental stress (alcohol, glare, etc.). However, might we have situations of too little stress (as defined above), boredom, and inattentiveness? These are issues to keep in mind as the research progresses.

Since our present concern is with environmental stress (and task overload to an extent), the critical issues remain of what stressors are causing accidents and how.

Environmental stress can come from various sources and, obviously, higher levels of stress lead to poorer performance. However, we should realize how adaptable man is to stress. The eye and the ear can tolerate changes in intensity and frequency that demand logarithmic scales because of their magnitude, without severely changing man's performance. Man is affected by heat, vibration, glare, etc., but not nearly so easily as computers and other devices of similar complexity. The astounding tolerance of man makes it even more critical that we discover where his limits are. As research continues we find these limits of performance are often reached before subjective feelings of discomfort are encountered. These are probably the areas of the most difficulty with respect to safety because the individual does not realize he has been influenced, and may not realize it even after an accident.

From the psychological studies of stress, a few more generalizations can be outlined. Different sources of stress are typically not additive in their effect but interactive. This demands that one investigate all stressors in a situation for their individual <u>and</u> <u>interactive</u> effects. For example, studies on information processing have shown that loss of sleep leads to poorer performance and high levels of environmental noise lead to poorer performance. However, when the two stressors were combined, the noise increased the level of arousal, compensating for the lack of sleep, and performance was <u>better</u> than under either stressor alone. The point? Stress should not be considered as a single thing, and stressor interactions should be studied as well as individual stressors.

Stress, then, is not a simple idea, but a complex one. The effects of stress are not static, but dynamic, i.e., they change as the task goes on. One formulation of this idea is the Yerkes Dodson Law, which claims that the optimal level of irrelevant stimulation increases as the level of task difficulty decreases. This suggests, for example, that as one learns a task, he can tolerate more and more stress while maintaining the same level of performance. In fact, more stress may be desirable to avoid boredom after learning. How might the Yerkes-Dodson Law apply to fatigue? It would predict that one could tolerate less stress under fatigue than otherwise. Thus, a certain amount of glare may not be a factor when heading out to fish, but <u>a lessor amount of glare</u>, after you've been fishing all day and are fatigued, may be a significant factor. Individual differences are important in stressor effects as well. Of critical importance then, is the complex nature of stress and stressor effects, and the ability of the individual to maintain his attention upon relevant information in the performance of his tasks.

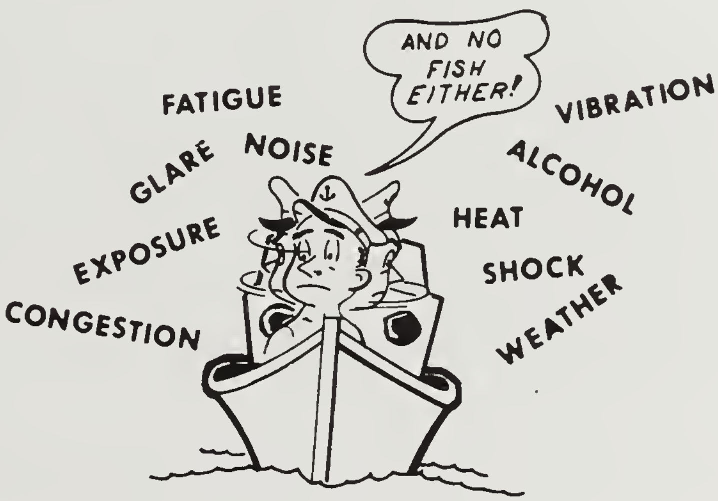


Figure 2. Operator Stressors

3.0 APPARATUS AND EXPERIMENTAL DESIGN

The previous section described the need for a divided attention task in the boating safety research area to probe stressors and their effects. The VAST program was an outgrowth of the Coast Guard's recognition of this need.

The critical elements of a divided attention task, as described in the previous section, are that it involve more than one task to be performed (a "primary" task and one or more "secondary" tasks) and that performance measures be readily available. One common usage of such a task, and the one that was proposed for this stressor research, is to use the performance measures to document continued good performance on the primary task while observing correlations between performance on the secondary task and experimental manipulations. VAST satisfies these requirements.

3.1 Experimental Apparatus

The original design for the VAST apparatus included the use of the actual steering of the boat as the primary task and some kind of target display in the boat cockpit as the secondary task. The subject would be required to steer the boat on a course dictated by the experimenter and do as well as he could at responding appropriately to certain target displays. The target display chosen was a 190° ring of 39 lights (5° spacing between lights). The display was designed to cover a wide range of visual angles, extending well into the peripheral field of vision of the operator. The light ring was covered to put the lights in a shadow and the entire housing was painted flat black. This made the lights visible even in bright sunshine.

The lights that were used were standard automobile accessory lights (comparable to bright brake lights). Figure 3 below illustrates the dimensions of the display.

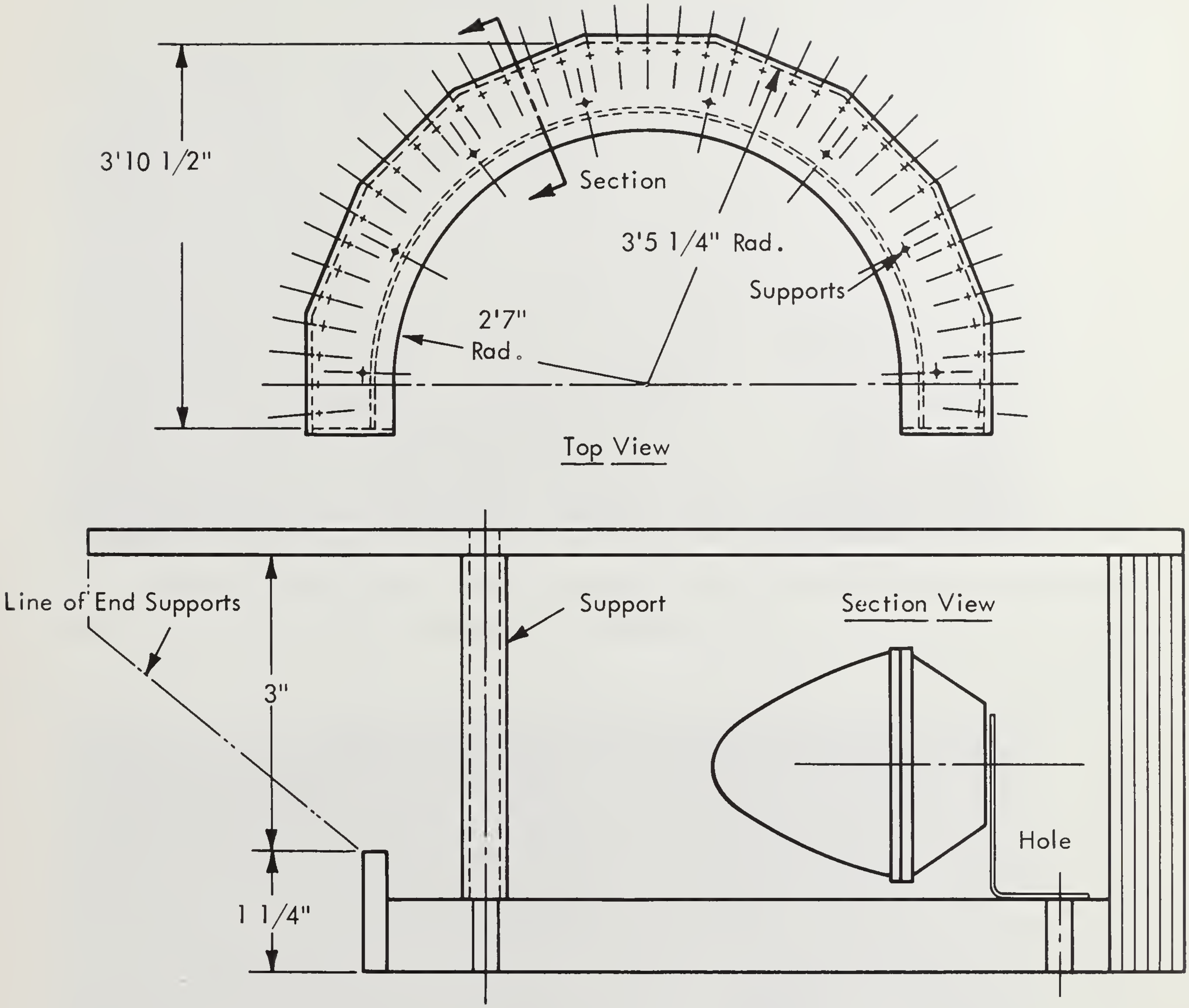


Figure 3. Light Display Dimensions

The display was mounted around the cockpit of the seventeen foot runabout as shown in Figure 1, Section 1.0. The cockpit itself was also adapted to provide adequate controls and displays for the subject and the experimenter. Figure 4 is a picture showing the throttle and response button. This was mounted on the subject's right-hand side, and all subjects were right-handed. The response button is the three position power trim button on the thumb side of the throttle handle. Depressing the button in either direction constituted a response.

Figure 5 shows the cockpit area as viewed from behind the throttle handle. The horn in the upper right of the photograph was used to signal the subject that he was off course. Below and just to the left of the horn is the tachometer. The subject was instructed to maintain a setting of 4000 rmp on this instrument but was allowed to change speeds in order to avoid other boats and bridges, to execute a course change, or to slow down if the wave conditions would not permit running at that speed. Directly in front of the steering wheel is the compass. The experimenter verbally called out course headings which the subject tried to maintain. The horn was blown at the experimenter's discretion. His tolerance was based upon the present conditions, the subject's responses (was he trying to get on course?), and our estimates from the training trials that most subjects could maintain a heading within 5 degrees.

The lights are embedded in the black ring above the steering wheel, tachometer, compass and horn. The small light attached to the bottom of the light display, behind and above the compass, is the program interrupt light. Whenever the program was not running (on the way to or from the test areas, or in heavy boat traffic), this red light was on to inform the subject that he need not worry about the lights but to concern himself with getting through the traffic to the appropriate destination. During the VAST test itself, this light was not on.

Figure 6 shows the cockpit area as seen from over the subject's left shoulder. The steering wheel, compass, program interrupt light, and light display ring are all clearly visible. The controls to the left of the steering wheel are the real power trim switch and other boat controls and displays.

Figure 7 shows the experimenter's handrail and control box. The experimenter stood behind the subject's left shoulder so he could hold onto the handrail and see the compass. The

Figure 4. Throttle and Response Button

Figure 5. Control Station Area

Figure 6. View Over Subject's Left Shoulder

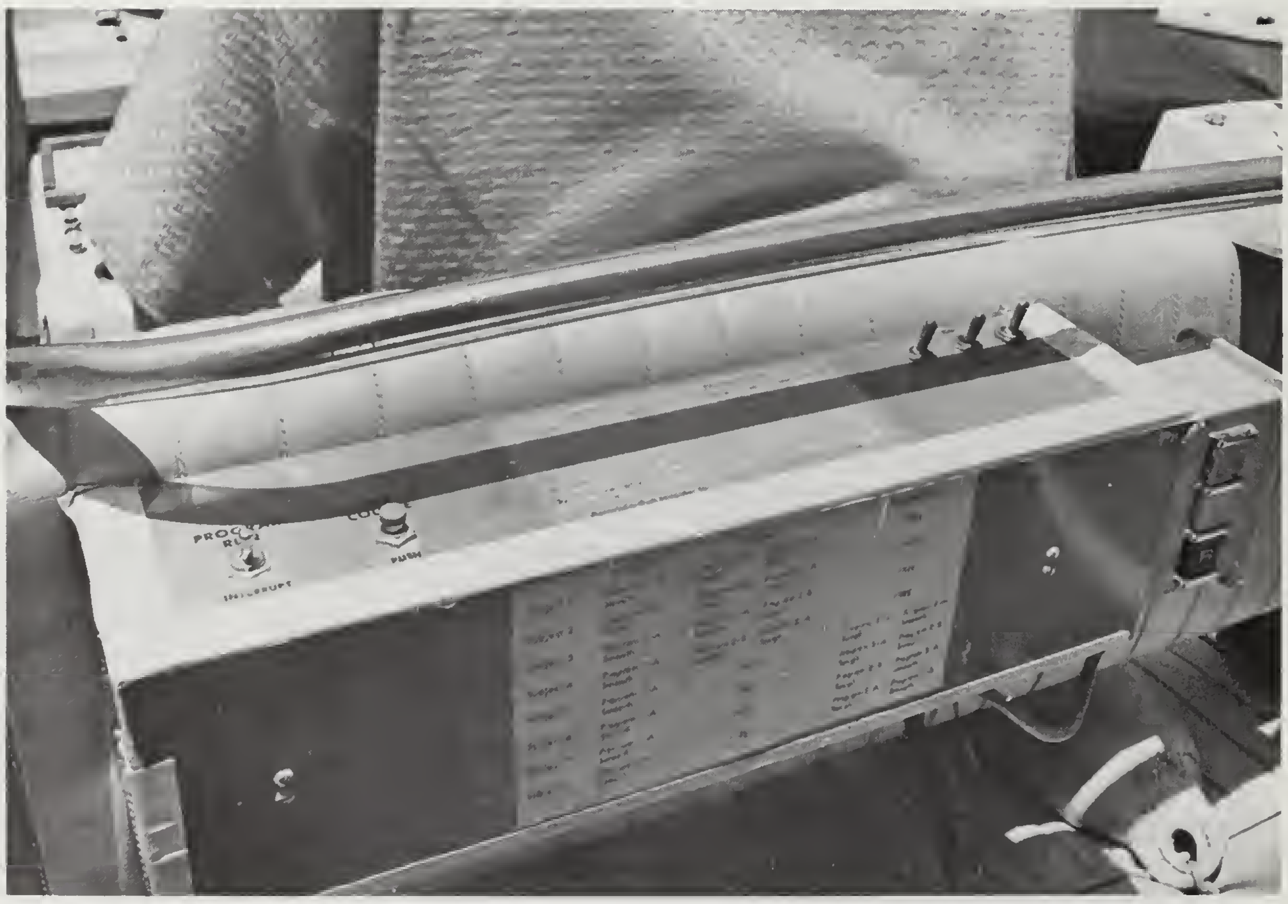


Figure 7. Experimenter's Control Station

switch at the far left of the experimenter's control box turns on the program (or interrupts it, depending upon the switch position), while the little button next to it blows the "off course" horn.

The switches on the right top of the box turned on the boat's instrumentation for transmitting and recording the required data. The small push buttons mounted on the right side of the experimenter's control box controlled the tape recorder. All subjects sat in the same position with the seat back fixed to minimize variations invisibility due to head positions.

Figure 8 is an aft-facing view of the cockpit and subject. In the foreground is the plywood cover to the computer and recorder. The picture also shows the extent of the light display (190°) and the visibility of the subject. The display is within a few degrees of the line of sight over the bow.

Figure 9 is a photograph of the VAST boat in action off the coast of Sanibel Island, Florida. The picture was taken during part of the fatigue cycle for the subject in the bow. The photograph shows the boat during the VAST test (although no lights were visible at this point) with the experimenter and subjects in their "running" positions. The cartoon in Figure 10 captures the essence of the afternoon fatigue runs.

Thus, the VAST apparatus presents the subject with light displays controlled by a mini-computer while the experimenter is dictating a course that the subject is trying to steer. We have described the primary task (steering the course according to the compass) and the secondary task apparatus. The secondary task itself is controlled by the computer programs.

The programs were designed to test the subject's peripheral vision, frontal vision, and information processing capabilities. Light patterns were programmed on three separate channels of the computer, right-to-left, left-to-right, and stationary, describing the movement of the corresponding patterns on the display. The channels are programmed independently, but the light patterns that are presented to the subject may involve two or more of these channels at once. The simplest pattern that is presented is a single light coming on steady for ten to twenty seconds. This could be any of the 39 lights, and the subject should respond to it as

Figure 8. VAST Apparatus Viewed From Bow

Figure 9. VAST Experiment Underway

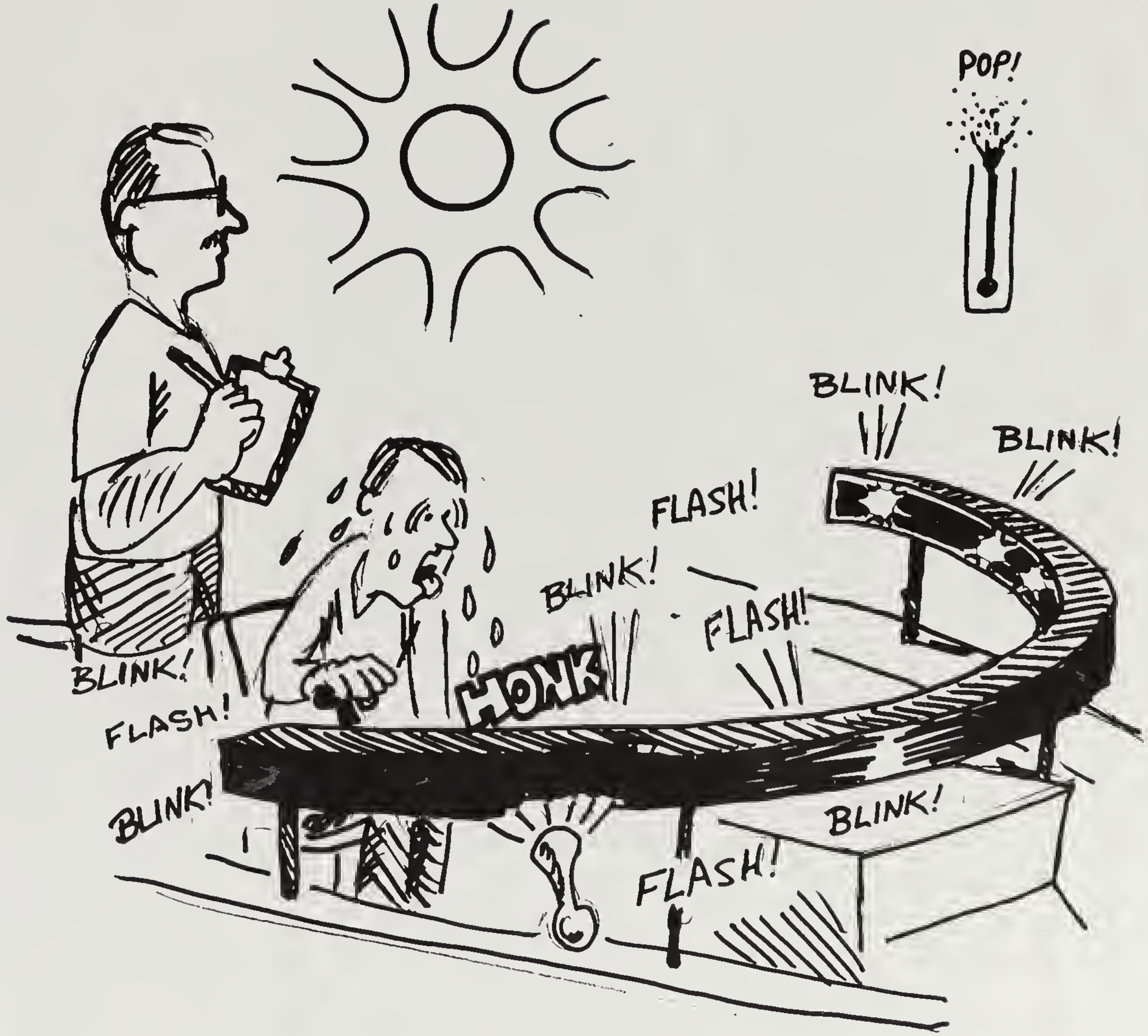


Figure 10. Cartoonist's View of VAST

soon as he senses that the light is not moving. That is, he should respond to any non-moving light, one that has always been stationary, or one that has been moving but stopped. The moving light patterns arise from the left-to-right and right-to-left channels. The channel may turn on any light (say, # 25) and move in the appropriate direction (say, right-to-left) any number of lights at either of two speeds (either 1 light per second, or 1 per every 1/2 second). When the movement stops, the light may go off, or it may stay on for 10 or more seconds (in which case the subject should respond as soon as he senses that the light is no longer moving). Since the three channels are independent, many light patterns are possible. The lights can move back and forth across the display (as if they represented a sailboat tacking), or several individual patterns can happen at once or in succession. Thus, the subject may have to respond to several fixed lights in one pattern, some stationary and some moving lights that have stopped. His attention may be drawn to one side of the display by a moving sequence while a stationary light comes on in another part of the display. Not all displays should be responded to. On occasion one or more moving sequences may be displayed which never stop at a fixed position before terminating. The subject is not supposed to respond to these, but only to fixed lights. It is readily apparent that the possible combinations are endless. Those that were used were designed to simulate (remotely) the movements of boats and objects on the water and be sensitive to mental fatigue as induced by the stressors. The timing between patterns vary from approximately one minute to almost eight minutes. Thus, the subjects never know when, or if, a pattern is coming, and there are long stretches of time without patterns on occasion. Two test programs were written (plus a practice program) to prevent the subjects from remembering test patterns in the afternoon test that they had seen in the morning test.

3.2 Experimental Design

How is the VAST apparatus used in the experimental design? The goal of this experiment was to determine if the entire realm of daytime stressors together have an effect on boating performance. Thus, the experimental design allowed the comparison of rested VAST tests (runs without or before exposure to the stressors) and fatigued VAST tests (runs after exposure).

The subjects were all male Coast Guard personnel. They were all between 5 feet 8 inches and 6 feet 3 inches tall, and between 155 and 235 pounds. The subjects ranged in age from 23 to 39, they all knew how to swim, and they all had some boating experience (most of them had more than 100 hours of power boating experience).

Since the experiment is designed to test for fatigue effects and stressor effects, learning by the subjects during the experiment could contaminate the results. If a subject's reaction times do not increase under fatigue, is this due to the lack of stressor effects, or the fact that the stressor effects were counteracted by improvements due to learning how to respond to the VAST apparatus? Thus, any learning effects that are readily apparent in the reaction time and error data would be grounds for excluding those data from the analysis of stressor effects. Obviously, the subjects must learn how to operate the boat, what the stimuli are, and how to respond to them before the experiment. For these reasons, each subject had a one half hour practice session on the VAST boat under test conditions, with stimuli similar to test stimuli, before his test day.

The subjects were then broken into two groups. One group would go through a "family" type of fatigue scenario, and the other would experience a "fisherman" oriented fatigue schedule. The experiement would last six hours for each subject (see Figure 11). The experiment would begin for each subject with one hour of preparatory activities. These activities were designed to include the general types of activities that a boater would undergo prior to going on the water, including driving on roads and highways with the boat trailered behind, and launching the boat from a marina launch. After the one hour of preparatory activities, the subject would drive the VAST boat for an hour on a course determined by the experimenter. While navigating this course, the subject would be exposed to the computerized light displays. This would constitute his first (rested) VAST test. The next three hours for this subject would involve general exposure to the elements. For those in the "family" group, the three hours would include shelling, playing softball, sunning, walking, and a little running. Lunch would also be eaten during this period. These activities were chosen to simulate the kinds of things one might do if he had driven for an hour to a location for a family outing.

<table>
<tr><th>TIME</th><th>SUBJECT 1</th><th>SUBJECT 2</th><th>SUBJECT 3</th><th>SUBJECT 4</th></tr>
<tr><td>8:30 - 9:30</td><td>Preparatory Activities</td><td></td><td rowspan="2"></td><td rowspan="3"></td></tr>
<tr><td>9:30 - 10:30</td><td>VAST TEST # 1 Program A</td><td>Preparatory Activities</td></tr>
<tr><td>10:30 - 11:30</td><td rowspan="3">Fatigue Scenario + Lunch</td><td>VAST TEST # 1 Program B</td><td>Preparatory Activities</td></tr>
<tr><td>11:30 - 12:30</td><td rowspan="3">Fatigue Scenario + Lunch</td><td>VAST TEST # 1 Program A</td><td>Preparatory Activities</td></tr>
<tr><td>12:30 - 1:30</td><td rowspan="3">Fatigue Scenario + Lunch</td><td>VAST TEST # 1 Program B</td></tr>
<tr><td>1:30 - 2:30</td><td>VAST TEST # 2 Program B</td><td rowspan="3">Fatigue Scenario + Lunch</td></tr>
<tr><td>2:30 - 3:30</td><td rowspan="3"></td><td>VAST TEST # 2 Program A</td></tr>
<tr><td>3:30 - 4:30</td><td rowspan="2"></td><td>VAST TEST # 2 Program B</td></tr>
<tr><td>4:30 - 5:30</td><td></td><td>VAST TEST # 2 Program A</td></tr>
</table>

Figure 11. Experiment Schedule for VAST
Test Day 1: Family Scenario

Almost half of this time was spent in resting or semi-resting activities, but in the sunshine. No sunglasses were worn. For the subjects in the "fisherman" group, the three hours were spent in water-related activities. These subjects spent the three hours in the sun, but on the water. The first two hours they would alternately motor one half hour and drift one half hour. The third hour would be spent riding in the bow of the VAST boat as another subject was making the test run. In Figure 11, the hour spent in the bow of the boat would be the one just prior to VAST Test #2 for each subject. Finally, after the three hour fatigue scenario, each subject would undergo the VAST test again, this time in a fatigued state.

Two test programs (A and B) were written so that a subject could not attempt to memorize particular patterns and their order or time of occurrence. As can be seen from Figures 11 and 12, these programs were counter-balanced so that if one program were fortuitously more difficult than the other, this would not prejudice the data.

With the VAST apparatus and experimental design now described, a brief discussion will follow of the data that were recorded. Reaction times, responses, and light patterns were recorded as the primary data. These measures would allow the major questions of the experiment to be answered via changes in reaction times and error rates, and an analysis of the types of errors made. The temperature and wind velocity were recorded periodically to document weather conditions. Other secondary data that were recorded included the direction (boat heading), motor angle, roll, pitch, vertical acceleration of the subject, and motor rpm. These data were collected to allow more detailed analysis of the subject's behavior on the VAST test. For example, a subject may have missed a light pattern because he was negotiating a turn.

The next section will present the results and data from the experiment off Sanibel Island, Florida, in April, 1975.

4.0 DATA AND RESULTS

In the previous section, two points were raised which centered upon the acceptability of the data. These included the investigation of the responses of the subjects for learning effects and the documentation of the weather conditions (to define stressor levels). We shall deal with the latter of these two first.

4.1 Weather Conditions

The temperature and wind conditions are shown in Table I.

TABLE I.

	Test Day 1		Test Day 2	
Time	Temp.	Wind	Temp.	Wind
10:00	80°F	E 14(18) mph	79°F	S 10(14) mph
12:00	86°F	SE 18(22) mph	85°F	SW 14(18) mph
14:00	90°F	S 14(20) mph	87°F	SW 10(16) mph
16:00	84°F	S 18(22) mph	87°F	SW 9(14) mph
Mean	85°F	16 mph	84.5°F	11 mph

4.2 Analysis of Learning Effects

The second issue was one of learning. If a subject was still learning how to perform on the VAST apparatus during the stressor tests, and that learning is apparent in his data, then those data could not be included in the analysis of the stressor effects since they would bias the result. This situation would result from the subject not having enough practice on the VAST boat.

Three types of data analyses were performed to test for these learning effects. Standard learning curves were drawn. The standard learning curve consists of a graph of each of the subject's responses against the chronology of those responses; i. e., graph the first response (reaction time), then the second, etc., until all of the reaction times for that subject's experimental sessions are graphed. Evidence of learning is demonstrated by a curve of the type shown in Figure 12.

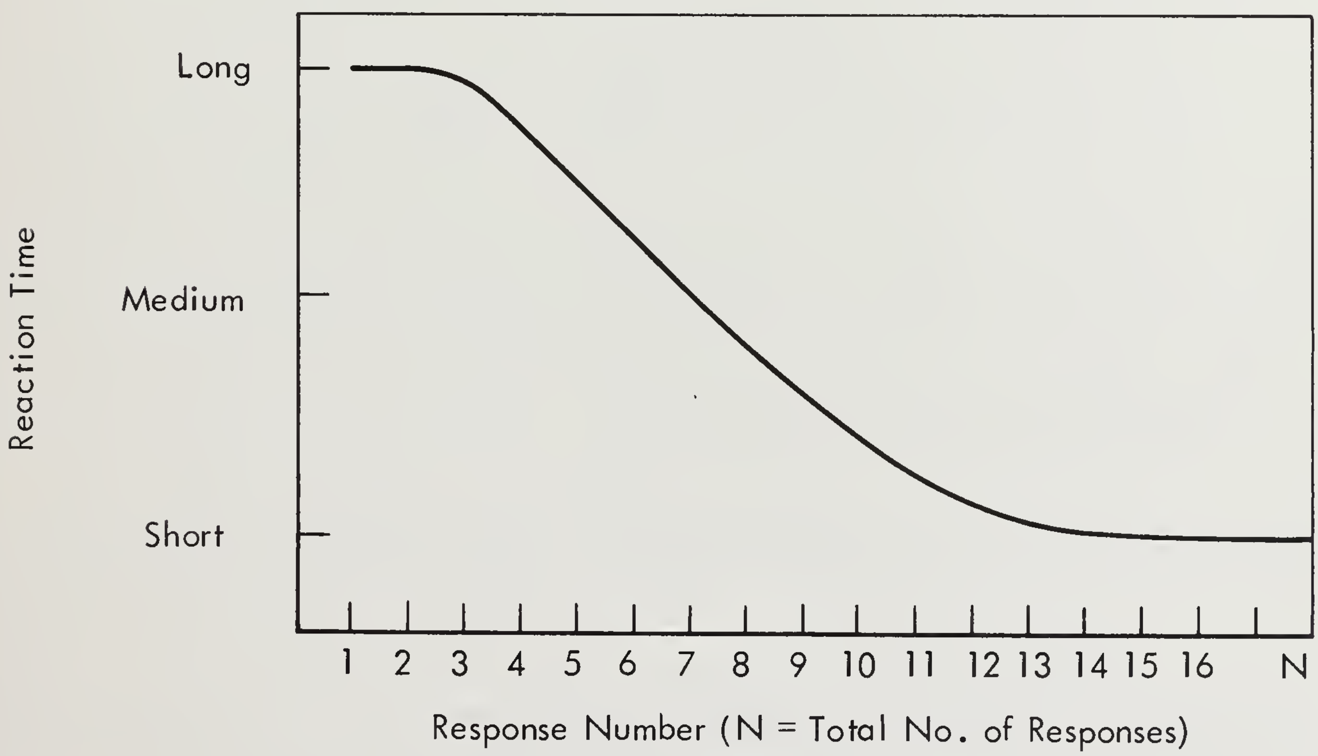


Figure 12. Typical Learning Curve

The actual shape of the curve may have a double inflection (as shown) or a single inflection. However, the trend is to continue to improve in performance (shorter reaction times represent improved performance) until a limiting value is reached where the subject has learned the task and improves very little with further practice.

With a novel task, such as VAST, it is not known at what point the subject has attained this learned performance level. It was hoped that the half hour practice session before the test days would be enough. The sign of a "learned" subject would be relatively stable performance at the beginning of the test day. This stable performance might be preceded by a couple of trials with slow reaction times. This is known as the "warm-up decrement." As the name implies, even learned subjects sometimes need a few trials to "get warmed up" and reattain their learned performance level. Figure 13 shows the learning curve for a typical learned subject experiencing a warm-up decrement in the first few trials.

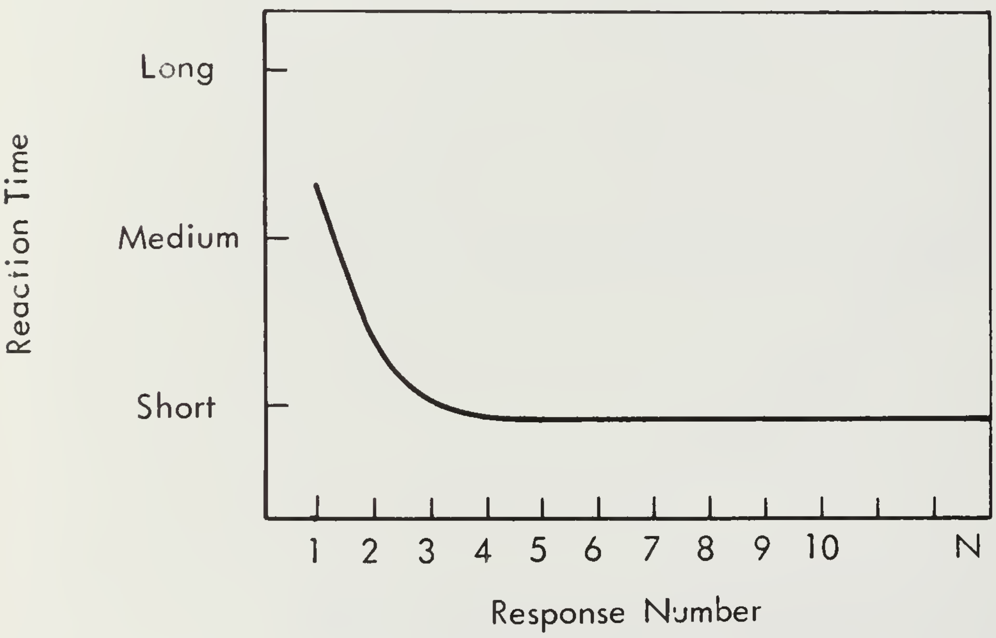


Figure 13. Warm-Up Decrement Learning Curve

Another type of learning curve is the step function learning curve. This is often used when individual responses (times) may be quite variable. In these curves the mean for a block of trials is used as the value of the function (or graph) for those responses. The number of reaction times (responses) in a block is often chosen to be 5 or 10 to make computations easier. Figures 14 and 15 show typical step function learning curve and a warm-up decrement step function learning curve, respectively.

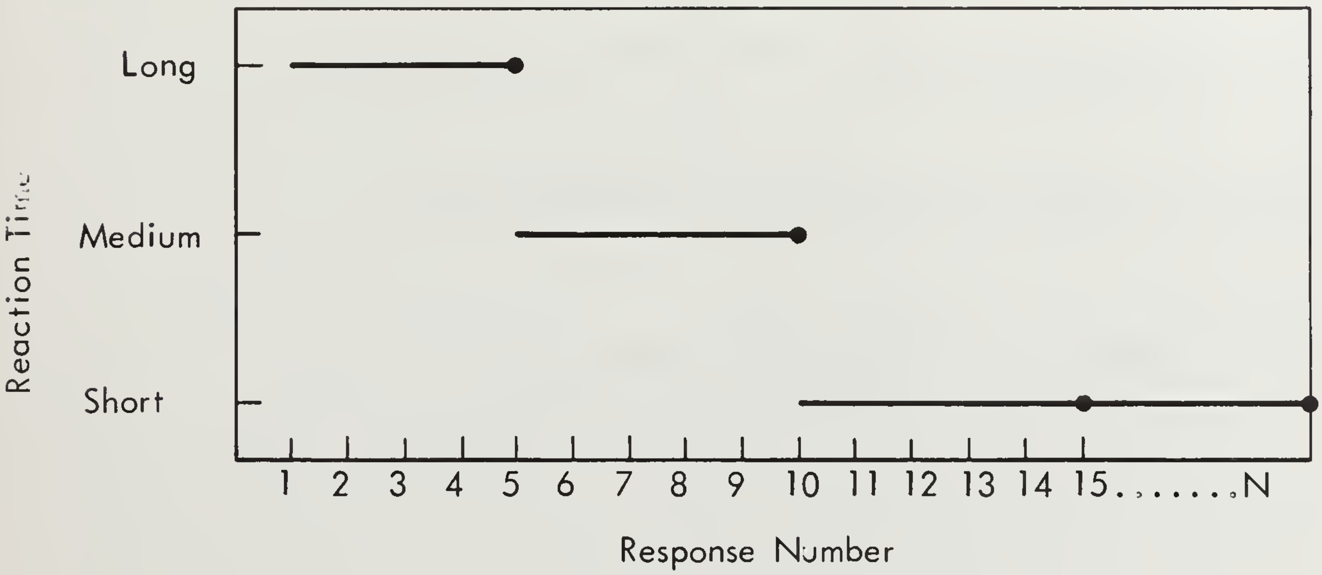


Figure 14. Step Function Learning Curve

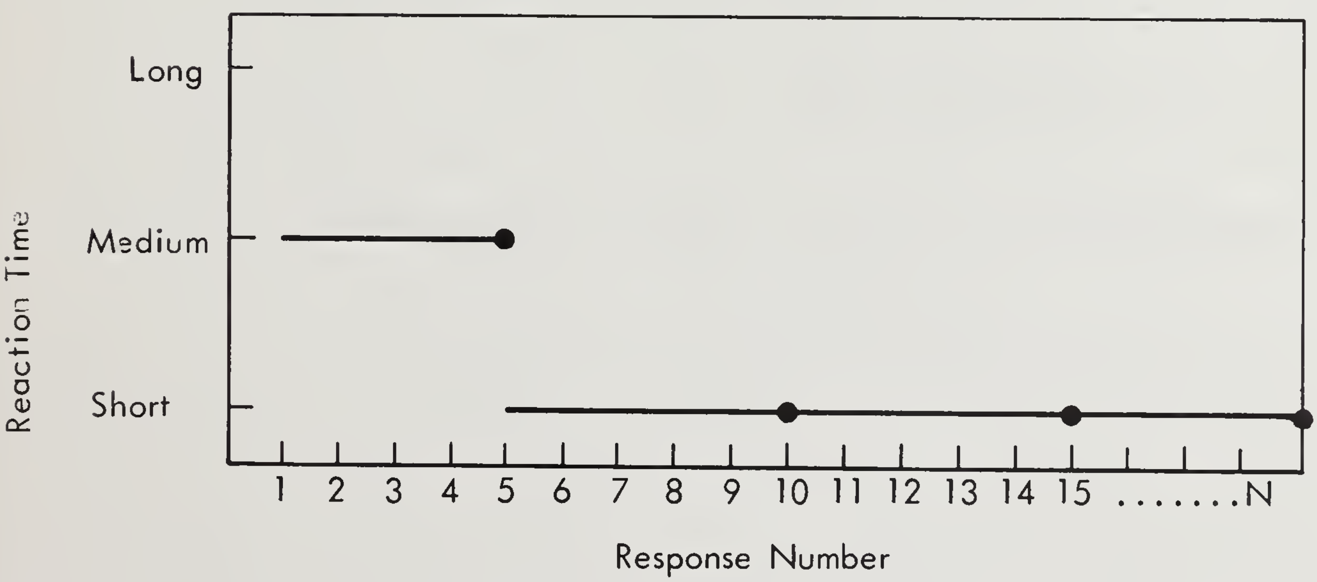


Figure 15. Warm-Up Decrement In A Step-Function Learning Curve

What should these curves look like if the stressors have a significant effect? Figures 16-1 and 16-2 showed an idealized conception of data from learned subjects who are subjected to stress after N trials.

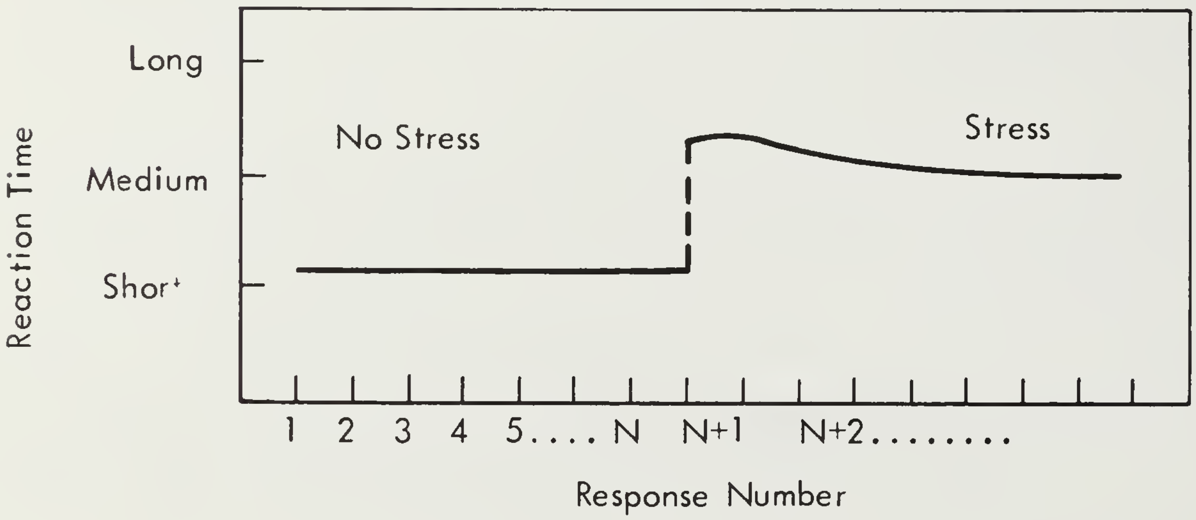


Figure 16-1. Learning Curve With Stress

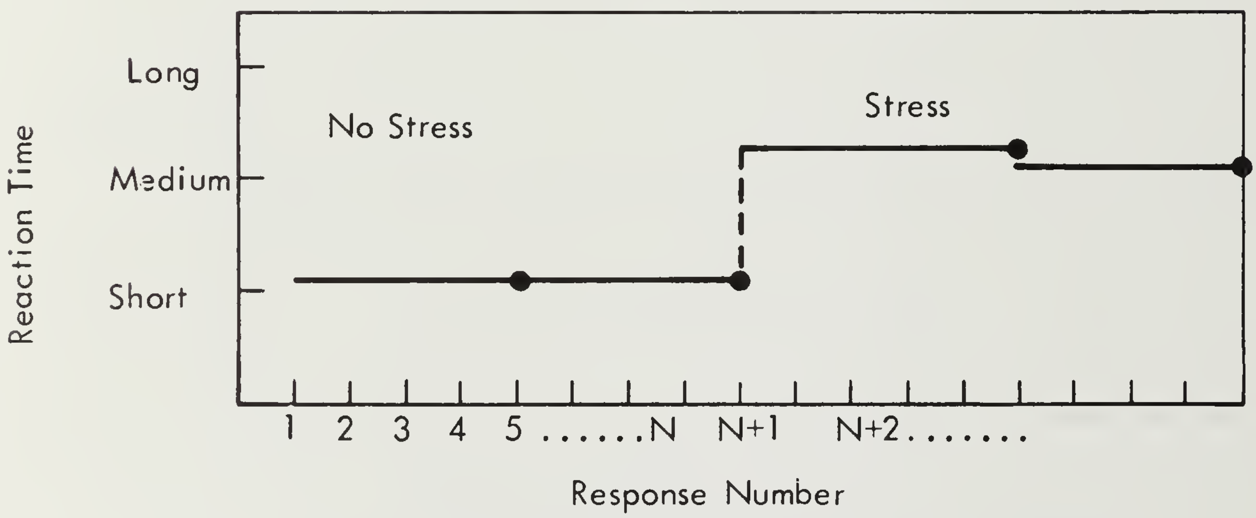


Figure 16-2. Step Function Learning Curve With Stress

Of course, all of these curves are theoretical and based on "average" or idealized responses. In truth, they indicate the trends in the data, subjects should be expected to vary around these curves.

The data themselves, the reaction times, are measured from the onset of the light that the subject should respond to to the beginning of the subject's response, in milliseconds. Thus, if a light comes on and 1500 milliseconds later the subject depresses the button on the throttle, then his reaction time to that light was 1500 milliseconds.

Finally, the subject's errors will be examined to determine learning effects there before proceding to the data analysis. If the subject makes a lot of errors early, and the number of errors decreases and the spacing between the errors increases, the subject is still learning to what stimuli to respond.

Figures 17-1 through 17-8 are the learning curves for the eight subjects in the VAST experiment near Sanibel. The data, in general, are variable. However, most of the subjects are relatively consistent in the 1000 to 3000 millisecond reaction time range, except for the "missed" signals which are counted as 20,000 millisecond reaction times instead of infinity (the 20,000 number was chosen since it is longer than the longest true reaction time which was 19,000 milliseconds). In any case, the only subjects where there is much evidence of learning are subject 4 and subject 6. From his learning curve, it is not clear that subject 4 ever learned the task. It should be remembered that these trials were <u>after</u> a full half-hour practice session earlier in the week. This subject obviously never learned the task, and his performance is far from approaching the relatively constant 1000 to 3000 millisecond response times of the other subjects. This argues for the exclusion of his data from the stressor analysis. Subject 6 also had difficulty with the task. His curve is not as obviously unacceptable as that of subject 4, nevertheless, it argues for the exclusion of his data as well. Note that he misses a lot of signals early in the session, and the spacing between these 20,000 millisecond responses is still increasing at the end of the day. Indeed, he appears to have learned by the middle of the morning session (around response # 10), and from here on in, his data do not look much different than those of the other subjects. This large number of missed signals in the beginning is more than just a warm-up decrement. This subject missed six of the first nine signals.

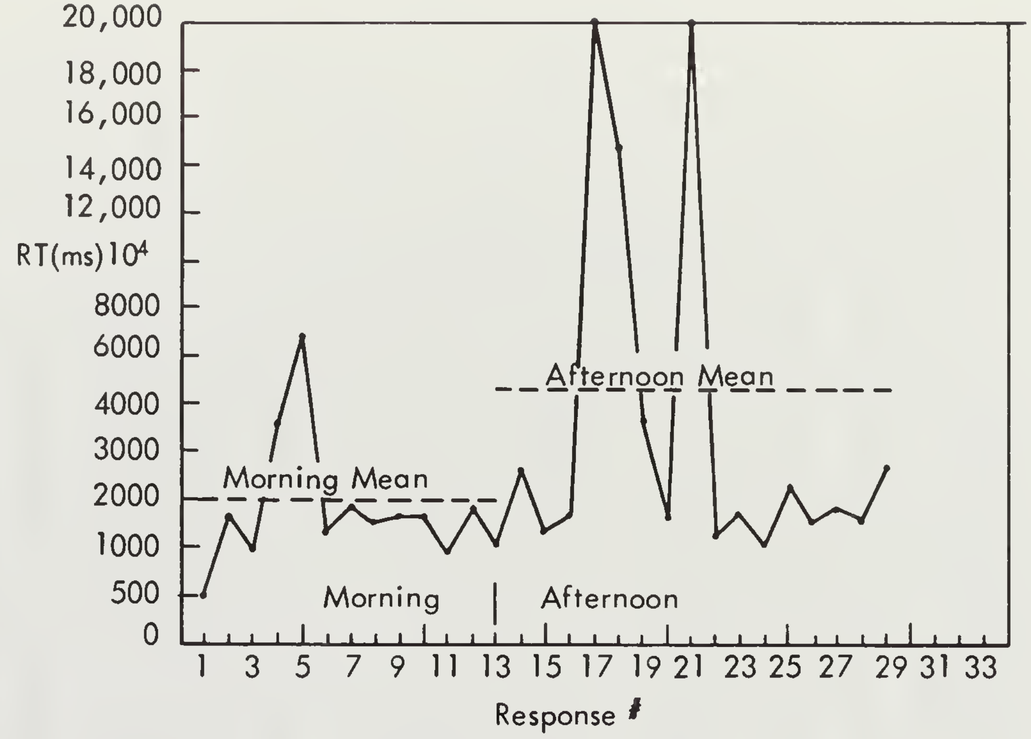


Figure 17-1. Learning Curve

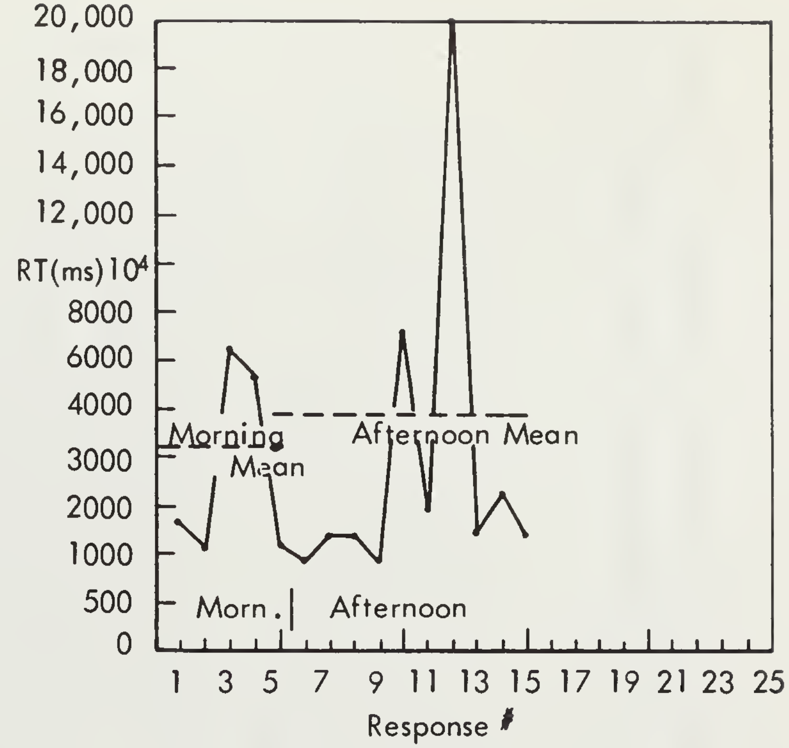


Figure 17-2. Learning Curve

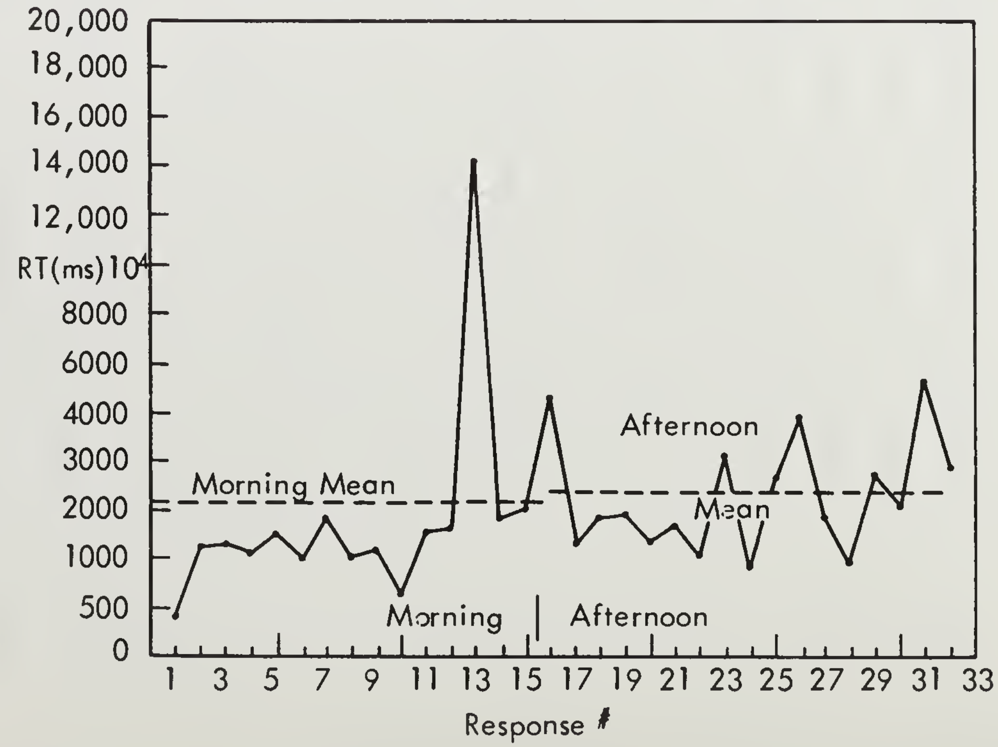


Figure 17-3. Learning Curve

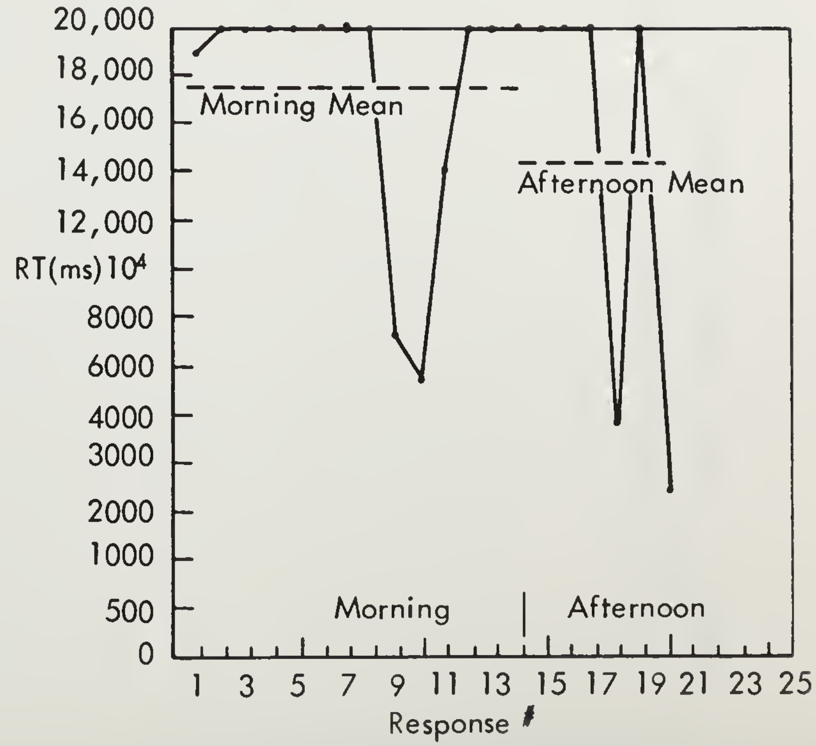


Figure 17-4. Learning Curve

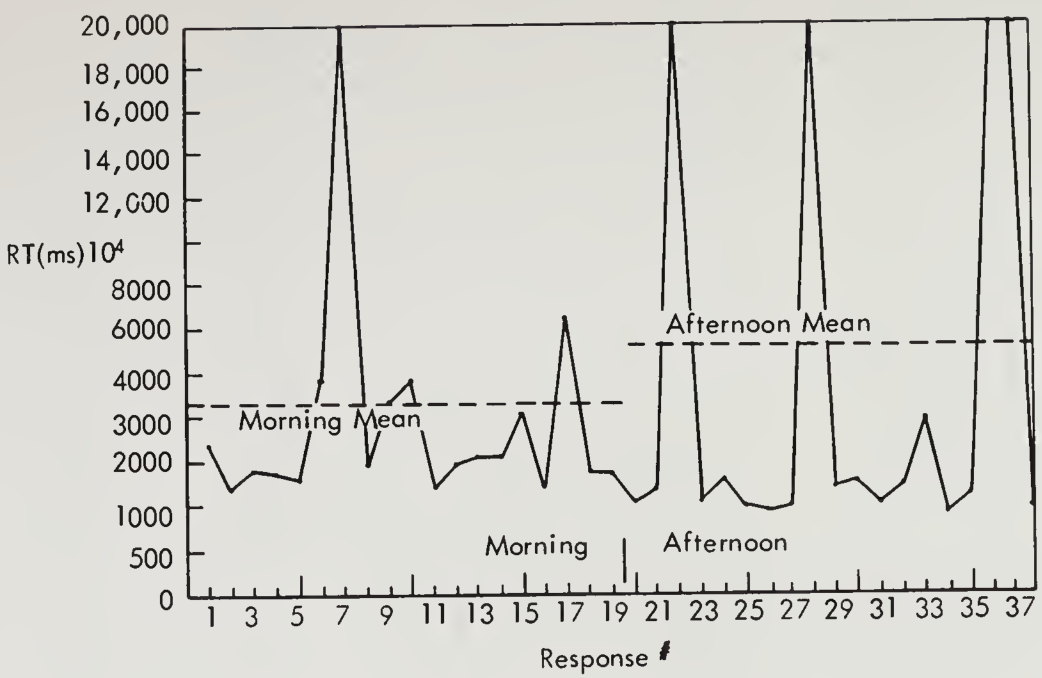


Figure 17-5. Learning Curve

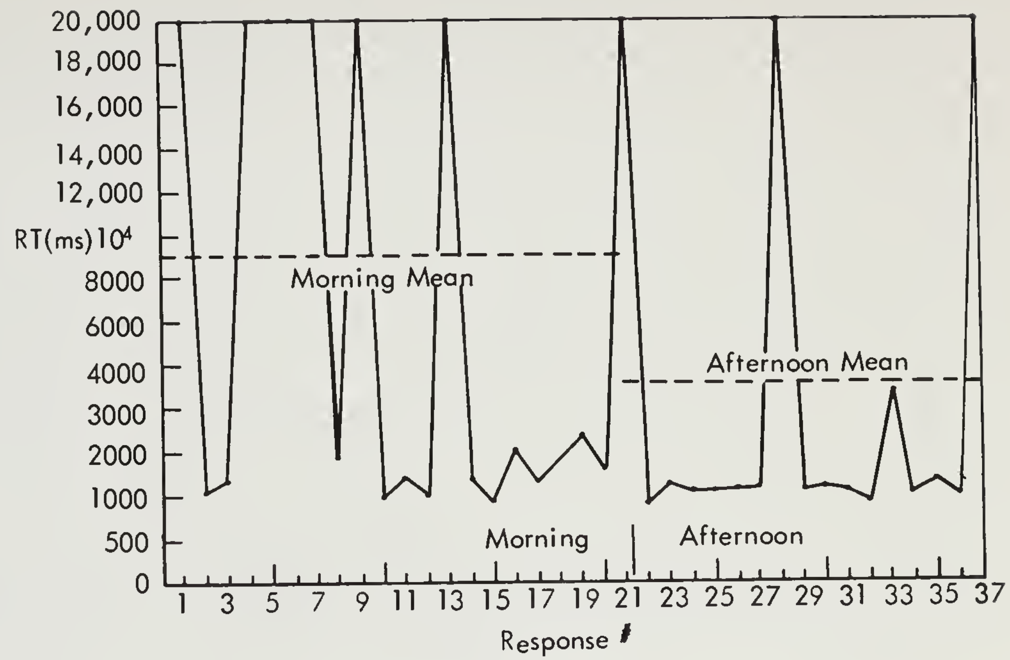


Figure 17-6. Learning Curve

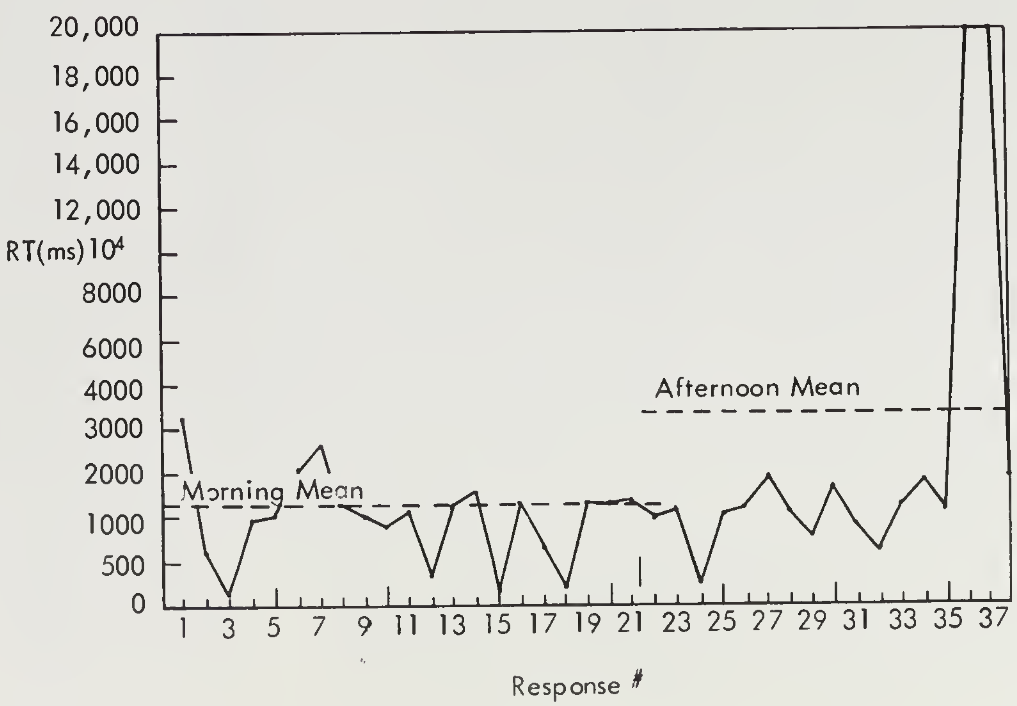


Figure 17-7. Learning Curve

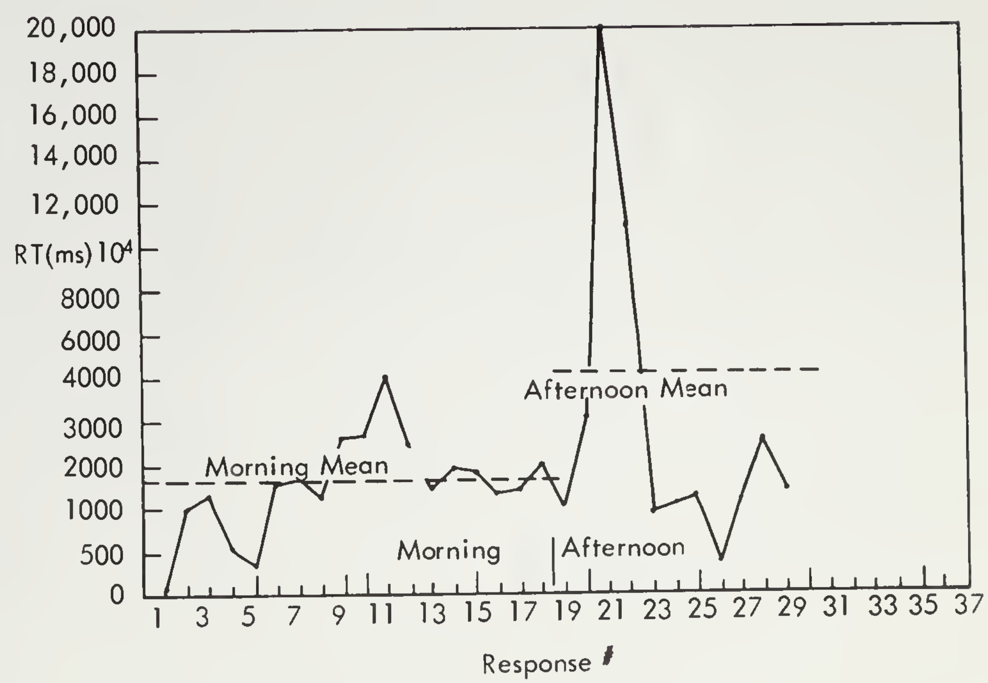


Figure 17-8. Learning Curve

The only other subject who missed so many signals in the early part of the session was the one who essentially never learned (subject 4). Although it appears that subject 6 learned the task during the test day, his data must be excluded because of this learning effect. If this subject had had a little more practice, he probably would have learned before the test day.

Figures 18-1 through 18-8 are the step function learning curves for the VAST subjects. Each "step" represents the mean of five response times (for the end of the day, this number may be 4 to 8 since not all subjects made the same number of responses). The step function learning curve for subject 1 is interesting in a couple of respects. The early part of the session contains some data resembling a warm-up decrement, and the later trials show some learning under stress, as if he were learning how to overcome some of his fatigue. Although these results are interesting, they do not call for the exclusion of his data since they do not show he was unlearned <u>at the start of his test day</u>, which is the criterion for excluding data due to learning effects.

Again subjects 4 and 6 have the learning data that call for their exclusion. For subject 4, the problem remains that he essentially has not learned, even by the end of the experiment. The first four "steps" of the curve for subject 6 (Figure 18-6) show a well-pronounced learning effect. Again, his performance after trial 10 or 15 looks comparable to the performance of the other subjects (see Figure 18-7). However, the early learning effect calls for the exclusion of these data from the stressors analysis.

In the analysis of errors, several things are important. At this point, in the discussion of possibly rejecting the data of subjects 4 and 6 due to severe learning effects, the critical issue involves the number of missed signals by each subject. If the subject does not respond at all to a stimulus that the task requires him to respond to, then he has not learned the task, or he was not sufficiently motivated to perform in the experiment. Table II shows the number of missed signals by each subject, broken down into morning and afternoon sessions. Subjects 4

TABLE II. NO OF MISSED SIGNALS: ALL SUBJECTS

Subject	S1	S2	S3	S4	S5	S6	S7	S8	Total
Morning	0	0	0	10	1	8	0	0	19
Afternoon	2	1	0	4	4	2	2	1	16
Total	2	1	0	14	5	10	2	1	35

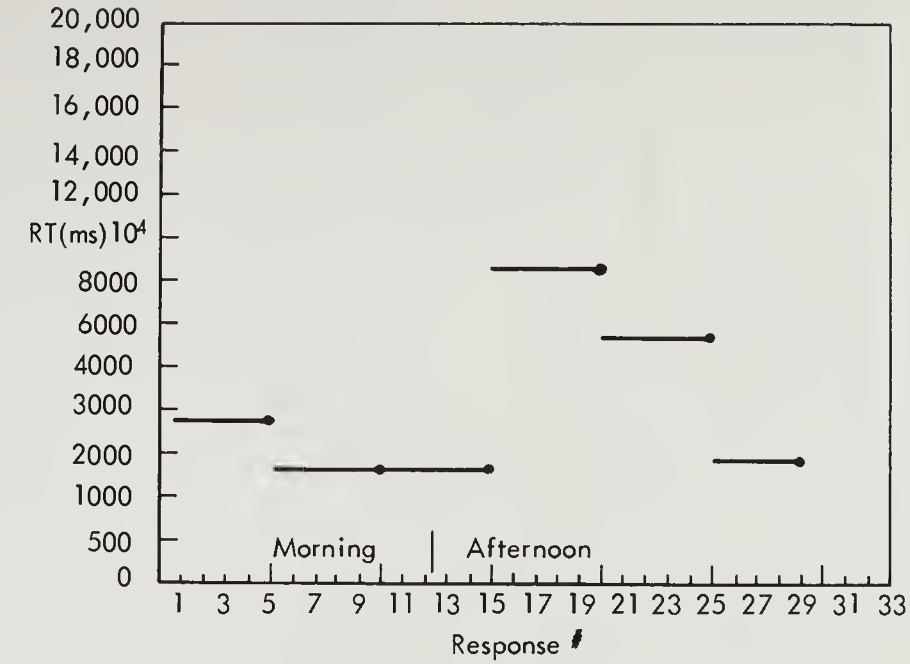


Figure 18-1. Step Function Learning Curve

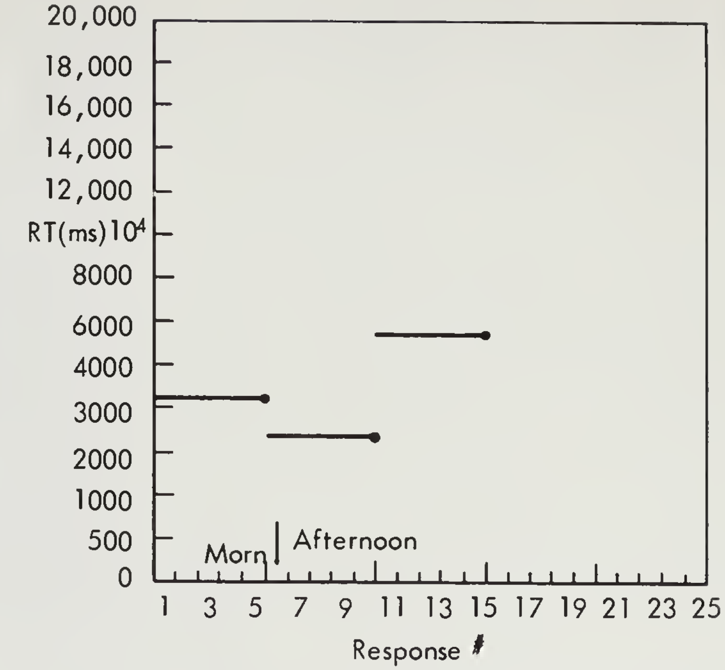


Figure 18-2. Step Function Learning Curve

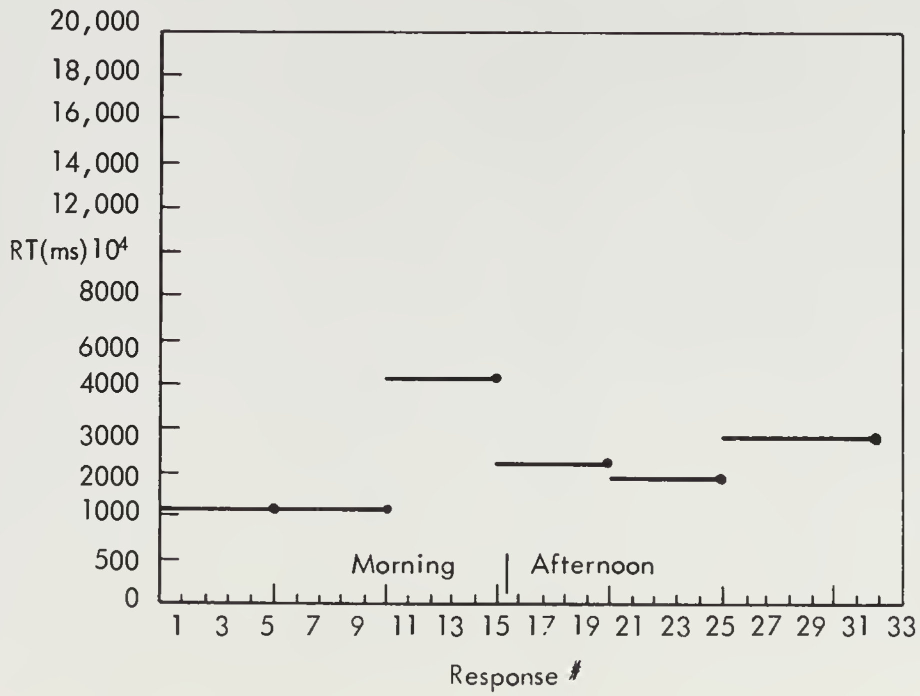


Figure 18-3. Step Function Learning Curve

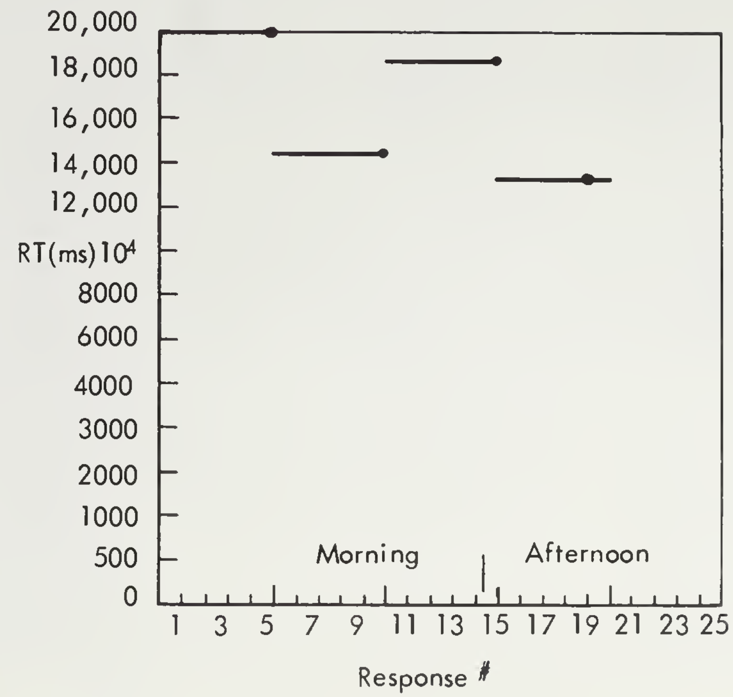


Figure 18-4. Step Function Learning Curve

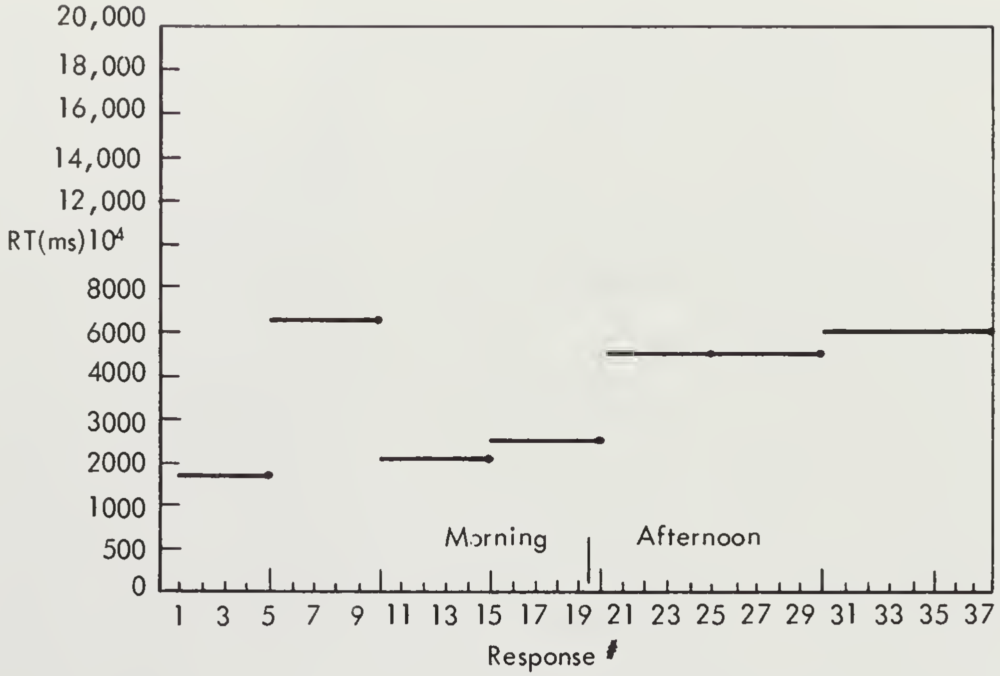


Figure 18-5. Step Function Learning Curve

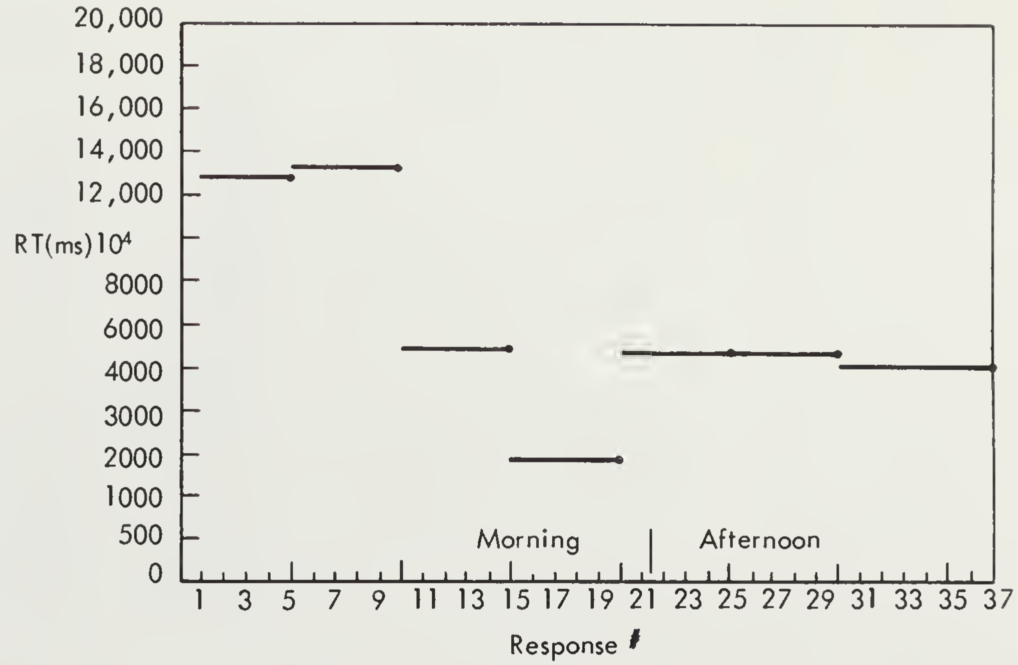


Figure 18-6. Step Function Learning Curve

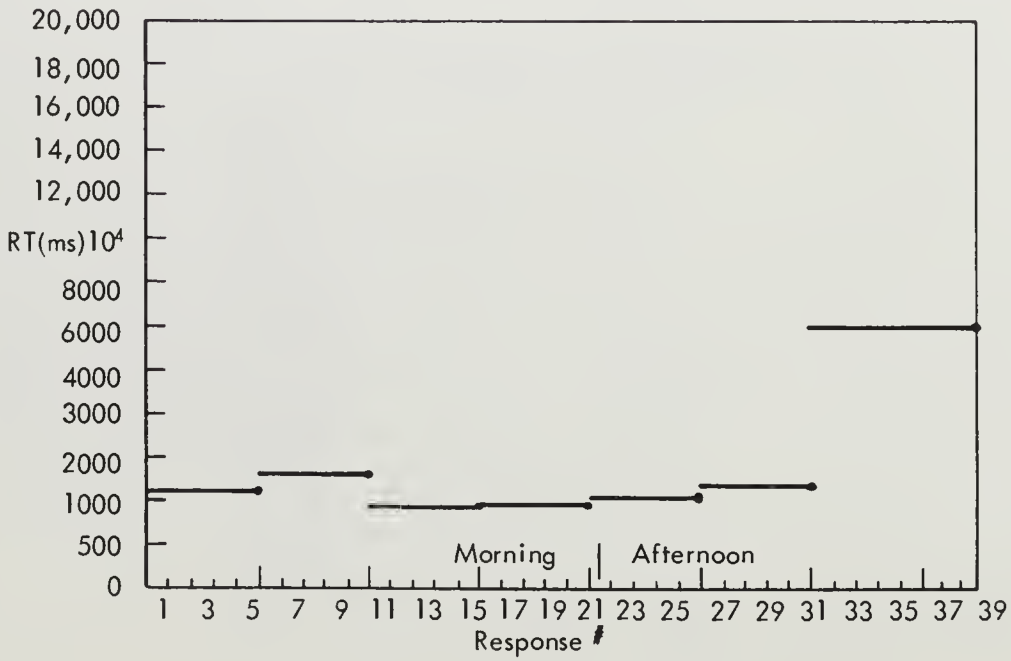


Figure 18-7. Step Function Learning Curve

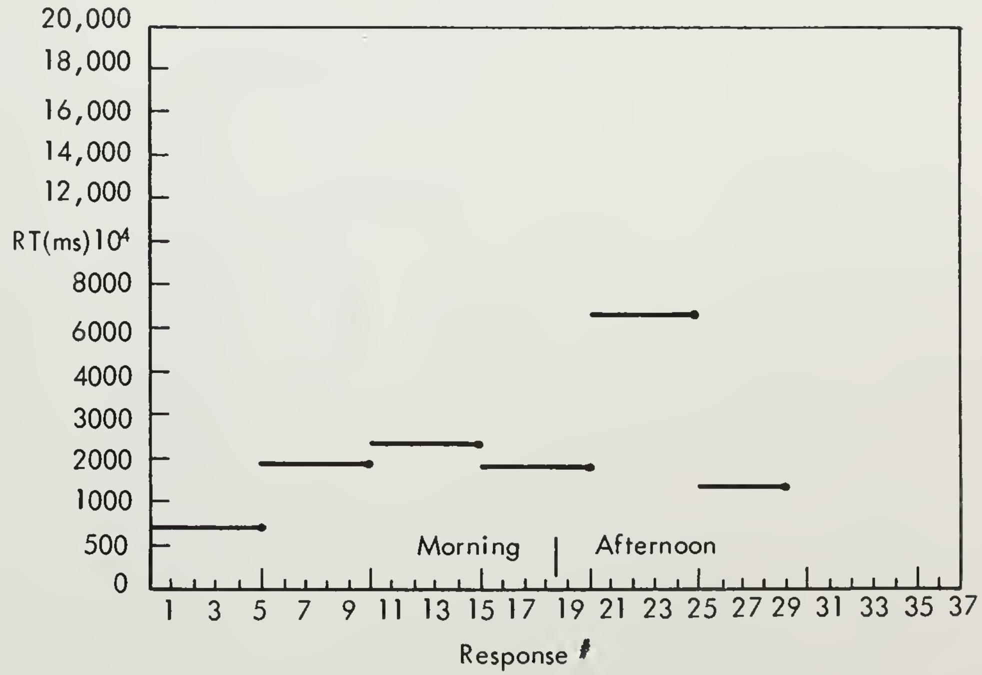


Figure 18-8. Step Function Learning Curve

and 6 are peculiar in their large number of errors in the morning session and large number of total errors. They both missed at least twice as many signals as any other subject. This fact, along with the time of their errors argues for the exclusion of their data from the stressor analysis. Some of the signals they missed were the easiest ones as well. Subject 4 missed light # 20, directly in front of him, when it came on for ten seconds.

Thus, all three measures: 1) standard learning curves, 2) step function learning curves, and 3) error data, indicate that the data for subjects 4 and 6 are unacceptable due to learning effects. What are the data from the other six subjects and what do they mean in terms of the experimental objectives?

4.3 Error Analysis

The data of Table II can be reorganized to include only the six subjects who had learned before the VAST tests began. This reorganization is shown in Table III. Table IV shows a F-test performed on these data to see if the 10 to 1 difference in missed signals was statistically significant. The data were converted to the proportion of errors for each subject since the subjects had different numbers of stimuli due to a computer malfunction. Since the observations are now proportions, then the variance and mean are related by:

Equation 1: $$\text{Variance} = \text{Mean}\,(1-\text{mean}),$$

and a scale transformation is in order. The specific transformation recommended in this case is:

Equation 2: $$X^1 = 2 \arcsin \sqrt{X + (1/2n)}.$$

(See Winer (1971), pp. 399-400). Table III-1 shows the raw data for missed signals and Table III-2 shows the transformed error data. An F-test was performed on these data and the results are shown in Table IV.

TABLE III-1. NO OF MISSED SIGNALS

Subject	"Family" Stress			"Fisherman" Stress			Total
	S1	S2	S3	S5	S7	S8	
Morning	0	0	0	1	0	0	1
Afternoon	2	1	0	4	2	1	10
Total	2	1	0	5	2	1	11

TABLE III-2. TRANSFORMED ERROR DATA

Subject	"Family" Stress			"Fisherman" Stress			Total
	S1	S2	S3	S4	S5	S6	
Morning	.411	.643	.367	.570	.310	.335	3.348
Afternoon	.787	.795	.345	1.016	.787	.756	3.774
Total	1.198	1.438	.712	1.586	1.097	1.091	7.122

TABLE IV. F-TEST ON PROPORTION OF MISSED SIGNALS: SUMMARY TABLE

Source	Sum of Squares	d.f.	Mean Square	F
Type of Fatigue	15123	1	15123	.278
$Error_1$	217509	4	54377	
Fatigued vs Rested	285208	1	285208	28.10, $p < .01$**
Interaction	58521	1	58521	5.77, $p > .05$
$Error_2$	40596	4	10149	
Total	616957	11		

An analysis of variance for a multi-factor experiment with repeated measures was performed on the transformed proportion data. The results show that the differences in the proportion of missed signals are statistically significant at the .01 level, relative to fatigued versus non-fatigued subjects. The other differences were not significant, and the F ratio for the interaction was relatively small (and not statistically significant).

Another type of response error the subject could have made was to respond to a moving light. This is known as a false response, because the subject should not have responded. There were no significant differences in the number of false responses across fatigue type or level of fatigue, but these differences would have been difficult to analyze even if they had arisen. They could have been due to the subjects forming a strategy to respond to everything so as not to miss a signal, or they could have been due to the subjects learning not to respond to moving lights.

With respect to the reaction times themselves, Table V shows the summary table for an F-test performed on the reaction times (in milliseconds). Since the subjects each had a different number of stimuli, an analysis of variance for a multi-factor experiment with repeated measures was used in the F-test computations (see Winer (1971), page 397ff).)

TABLE V. F-TEST ON REACTION TIMES: SUMMARY TABLE

Source	Sum of Squares	d.f.	Mean Square	F
Type of Fatigue	22,274	1	22,274	.014 not significant
$Error_1$	6,239,545	4	1,559,886	———
Fatigued vs Rested	8,702,330	1	8,702,330	19.51 significant $p < .025$
Interaction	670,714	1	670,714	1.50 not significant
$Error_2$	1,784,043	4	446,011	———
Total	17,418,906	11		

The results for the reaction times were essentially the same as the results for the error scores; i.e., there was a significant effect of exposure to the stressors, but there was no interaction effect, nor was there a significant effect of the fatigue scenario (family versus fisherman). This last fact means that the components that the two fatigue scenarios had in common were the important ones, these caused the overall fatigue effect. The components where they differed had no apparent effect. Thus, the elements of fatigue which seemed to have an effect were glare, heat, noise, vibration (during the test runs), wind, water conditions (during the test runs), and the computer program. The elements which did not have an effect were the drifting, motoring, and riding in the bow as opposed to the very light exercise on the beach

by the "family" stressors group. Thus, the fatigue effect appears to be less dependent upon physical demands, since the irrelevant parameters were the more physical ones. It is possible that a major component to fatigue is a degradation in information processing, because the light activity and exposure had the same gross effect as the more vigorous physical activity of the fisherman's scenario.

The lack of an interactive effect further confirms these ideas. The elements of the two fatigue scenarios that were shared had a consistent and statistically significant effect. The mean reaction time when rested was slightly more than 2100 milliseconds, and the mean reaction time when fatigued was 4000 milliseconds. The same effects were found in the error scores. In neither case did the type of fatigue or the interaction of the type of fatigue with level of fatigue have any effect. Thus, the fatigue effect in this study was clear cut, important, and not complicated by interactions.

The results also show that the VAST system is sensitive to performance degradations attributable to fatigue. Six of the subjects learned to operate the system with only a half hour of practice, and a seventh learned by the first few minutes of his first run on the test day. After this point (see response number 15 and following in Figure 10-6), his data look like those of the learned subjects (near 2000 milliseconds reaction times "rested" and near 400 milliseconds reaction times "fatigued"). Thus, the subjects could master the task. The fact that the results show a large fatigue effect and no interaction speaks well for the sensitivity of the apparatus and experimental design.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The two important findings of this initial VAST experiment were 1) that the combined daytime stressors (heat, glare, noise, waves, etc.) did have an effect on performance, and 2) that the VAST apparatus and experimental paradigm were sensitive to the effect. It should be noted that there is a difference between statistical significance and importance. While there may be a statistically reliable difference in the average distance of a Hank Aaron home run as opposed to a Mickey Mantle home run, the difference is probably not important since the end result of any home run is the same. In the present case, the average difference between rested and fatigued subjects on the VAST task was almost two seconds. A little later on, the discussion will include a comparison of this finding with similar results in other areas, such as alcohol. However, the issue now is, is the two second difference important?

The two second difference on VAST may not represent the true magnitude of the stressors effect in "real time." The VAST task is a quick response task. All the subject must do is decide if he has seen an appropriate stimulus, and if so, push a button. The stimuli are complicated, but simpler than the real stimuli of boats. With the lights, there was no depth perception, no glare on the target, no visual obstructions, etc. The response was also easier. It's certainly much easier to push a button than to decide upon a maneuver to execute and then do it. Thus, the measured two second difference underestimates the true difference in real time. In addition, a boat travelling 30 miles per hour will travel 44 feet in a second. A time difference of two seconds due to fatigue (which, from the previous discussion, is a conservative estimate) would mean the boat would travel an additional 88 feet before the operator could react. How many accidents might have been prevented or avoided if the operator had reacted 88 feet sooner? Obviously, this kind of a difference could be important.

Of greater importance are the trials that contributed greatly to the difference in the experiment. These were the afternoon (fatigued) trials where the subject failed to respond to a signal. The subjects missed 10 signals in the afternoon and only one in the morning. Thus, the important difference might be the tendency to miss signals (perhaps "miss" another boat) under fatigue. This means not just a delay in the response but no response at all. The fatigue or stressor

effect may be one reason why so many boaters say, after a collision, "I never saw the other boat," or, "He didn't have his lights on." The effect of causing the boater to miss signals, or other boats on the water is very important indeed.

To indicate the relative size of this effect (the change from 2.1 second average reaction time when rested to 4.0 second average reaction time when fatigued). Various studies on alcohol and reaction times have been performed. Huntley (1973) found that the interaction of alcohol and stimulus uncertainty (not being certain where the stimulus will occur) produced a reaction time degradation of about 100 milliseconds. Moskowitz (1971) found a 400 millisecond increase in reaction times with alcohol levels of 0.07 percent BAC (a legal drunk is 0.10 percent BAC). Mortimer and Jorgeson (1971) found an increase in eye movement time (related to visual detection time) of 250 milliseconds under the influence of 0.10 percent BAC. All of these experiments involve laboratory or simulator testing of the effects of relatively high quantities of alcohol, and yet, none of their results approach the nearly 2000 milliseconds effect of fatigue that was found in this initial VAST experiment, although the adding of eye movement time, central processing time, etc., may correspond to this total effect. Another interesting comparison involves the feelings of the subjects about their performance. With alcohol, subjects often feel as if they performed better than without alcohol. In our experiment subject 8 commented that he thought he had done better in the afternoon (fatigued) even though Figure 18-8 shows degraded performance in the afternoon. This is one of the dangerous aspects of stressors; the subject may believe his performance is improved when it is impaired.

5.2 Design Modifications

Several amendments to the apparatus and experimental design are needed to solve some of the problems that arose in Florida. Figure 19 shows one of these modifications.

The subject should be informed when he has responded correctly and when he has responded incorrectly. This will help him to learn faster and it will prevent him from deciding to respond to everything, in case what he saw might have been a steady light. Figure 21 shows a windshield washer arm mounted to the light display with a "reinforcing" stimulus attached. This arm would become visible when the minicomputer recognizes a correct response from the

Figure 19. VAST Feedback Modifications

subject. The arm would not be visible otherwise. When an incorrect response is made, the throttle handle would vibrate and buzz to signal the error. Thus, the subject will know about his performance as the test progresses.

Additional modifications will include stimuli to signal the beginning and end of the computer program, and changes in the programs if they are needed. Some of the subject variability can be reduced by making the light patterns more similar, this would increase the device's sensitivity (since it would decrease the within subject error).

5.3 Future Applications

The results from this initial experiment are encouraging. They indicate that stressor effects may be oriented more toward mental processing effects than toward physical effects. The stressors of glare, heat, noise, vibration, waves, wind, and information processing load (via the program) combined were shown to have a significant effect on performance, so it is time to begin to break out the individual stressor effects and interactions. Research is underway at Wyle to analyze the effect of alcohol on boating performance, and the interaction of alcohol with the stressors used in Florida. The VAST study will essentially be replicated with alcohol as an additional stressor, and deleting the "type of fatigue" variable (we will use the "family" scenario since it involves less equipment and monitoring).

The experimental design will be done in a 2 x 2 factorial design with two levels of alcohol, and two levels of fatigue, to measure the effects of alcohol alone and combined with other stressors. Such a study could result in significant contributions to our knowledge of stressor effects in boating (particularly, alcohol) and to developing a scale of stressor effects by comparing the relative sizes of induced VAST performance degradations. Three groups of subjects will be needed. The two alcohol levels will be 0.00 percent and 0.10 percent BAC. The two levels of fatigue will be rested and fatigued. Group 1) will be the controls, with no alcohol, Group 2) will be given alcohol before the morning (rested) test and their data will be compared with the morning (rested) data from Group 1 to determine the effect of alcohol alone, Group 3) will be given alcohol before the afternoon (fatigued) test as an additional stressor. Their data will be compared with the afternoon (fatigued) data from Group 1 to determine the interactive effects of alcohol with the other stressors. In addition, Group 3 will be given a

placebo before their morning tests. The comparison of their morning data with those of the other groups will allow an analysis of the psycho-social effects of drinking per se on performance on VAST.

Further studies are in the planning stage to isolate other stressors such as noise, glare, and heat. For some of these (noise, for example), laboratory studies may be needed to define appropriate stressor (noise) levels for the follow-up field studies. These experiments will involve some modifications to accommodate particular stressors, but the basic VAST experiment can be run to determine the stressor effects. Thus, VAST is applicable in many of the areas where collision research is needed.

APPENDIX III-B

STOPPING DISTANCE AND TURNING RADIUS vs. SPEED FOR A SAMPLE OF RECREATIONAL BOATS WITH OWNERS DRIVING

1.0 INTRODUCTION/SUMMARY

Recognizing the fact that collisions of one type or another represent a significant portion of recreational boating accidents, it was considered beneficial to investigate boat/operator reaction capability for stopping in a collision avoidance maneuver. The experiment reported herein was accomplished through the cooperation of the Huntsville Power Squadron in order to obtain a cross section of boats as well as to determine how an operator, familiar with his own boat, might react in an avoidance maneuver. The boats selected for the test were of various hull forms and ranged in size from 15' through 41'. Eight boats, loaded as they are normally cruised, were run through a test course by their owners. In addition, Wyle personnel ran three USCG test boats through the same course. Speeds, stopping distances, and turning diameters were recorded during the tests.

2.0 BACKGROUND

Considering the three basic maneuvers in an avoidance situation of 1) cutting the throttle or trying to stop, 2) turning away from the object, and 3) combination of turning and stopping, a course was designed (see Fig. 1) to measure the ability of the boat/operator system to accomplish the avoidance maneuvers. The operators were asked to run their boats through the collision avoidance course in the following manner: 1) Hold a straight course to determine speed and then at the predetermined mark, cut the throttle to determine stopping distance. Three different throttle settings were used for this test. It should be noted that drivers were not asked to reverse engines in stopping: therefore, boats were not dead in the water when observed as being "stopped." 2) Best turn to starboard at a predetermined point at the same three throttle settings. 3) Best turn to starboard when the throttle is cut from the same three throttle settings.

3.0 DATA ACQUISITION

Speed was determined by radar. Stopping distances and turning diameters were observed and recorded by two observers. The first diameter recorded being that of the first observer

and the second diameter or "down to" diameter being that of the second observer (Fig. 1). Boat weights were established from available specifications and owner's knowledge. In addition, photographic documentation was accomplished throughout the experiments. The data acquired are presented in a condensed chart form in Table 1. Curves plotting speeds vs. stopping distances and turning diameters, and weights vs. stopping distances and turning diameters are presented in Fig. 2-5.

4.0 SUMMARY

4.1 Stopping Distances

The time the hull stays on plane is the determining factor on distance travelled after power cut. Lighter boats in the 25-40 MPH range stay on plane longer and travel the longest distance: however, heavier boats travel further in the displacement attitude. Most dangerous boats appear to be the lighter 25-45 MPH boats that stay up on plane for a considerable time after the power is cut. Some drive trains may not "free wheel" as easily as others which in turn would contribute to the boat's stopping ability.

4.2 Turning

All of the boats tested were propeller driven: therefore, the turns that were executed before the throttle was cut or without cutting the throttle were generally better than when the propeller thrust was lost before turning. Turning and then cutting the throttle will provide better avoidance in most cases. It should be pointed out that prop rotation enters into turning capability. All of the test boats but one had right hand props; therefore, the turn to starboard, which was executed in the tests, would not be the best turn. A right hand prop driven boat should turn better to port.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Although it is difficult to draw any finite conclusions from a test of this nature, the general capabilities of a boat to turn and/or stop in a collision situation were established. The difficulty in trying to stop without going into reverse gear was clearly pointed out. Although this emergency stopping or reversing while underway is a requirement on many commercial vessels, it is not normally considered a requirement for pleasure craft. Many drive systems on pleasure craft could not meet this severe requirement. In future turning or avoidance tests, it is recommended that effort be expended to determine how far the boat continues on a straight line course or just clears an obstacle after the initial steering input. In other words, the first 30° of course change is considered more important in an avoidance situation than the total 180° change which was measured during this experiment.

All the boats could be stopped (by throttle cut) in about 230 feet at full throttle. The heavier boats were essentially stopped at about 150 feet. The faster, lighter boats took longer.

Turning radiis ran from 50 feet at lower throttle setting up to 260 feet at full throttle (minimum-maximum).

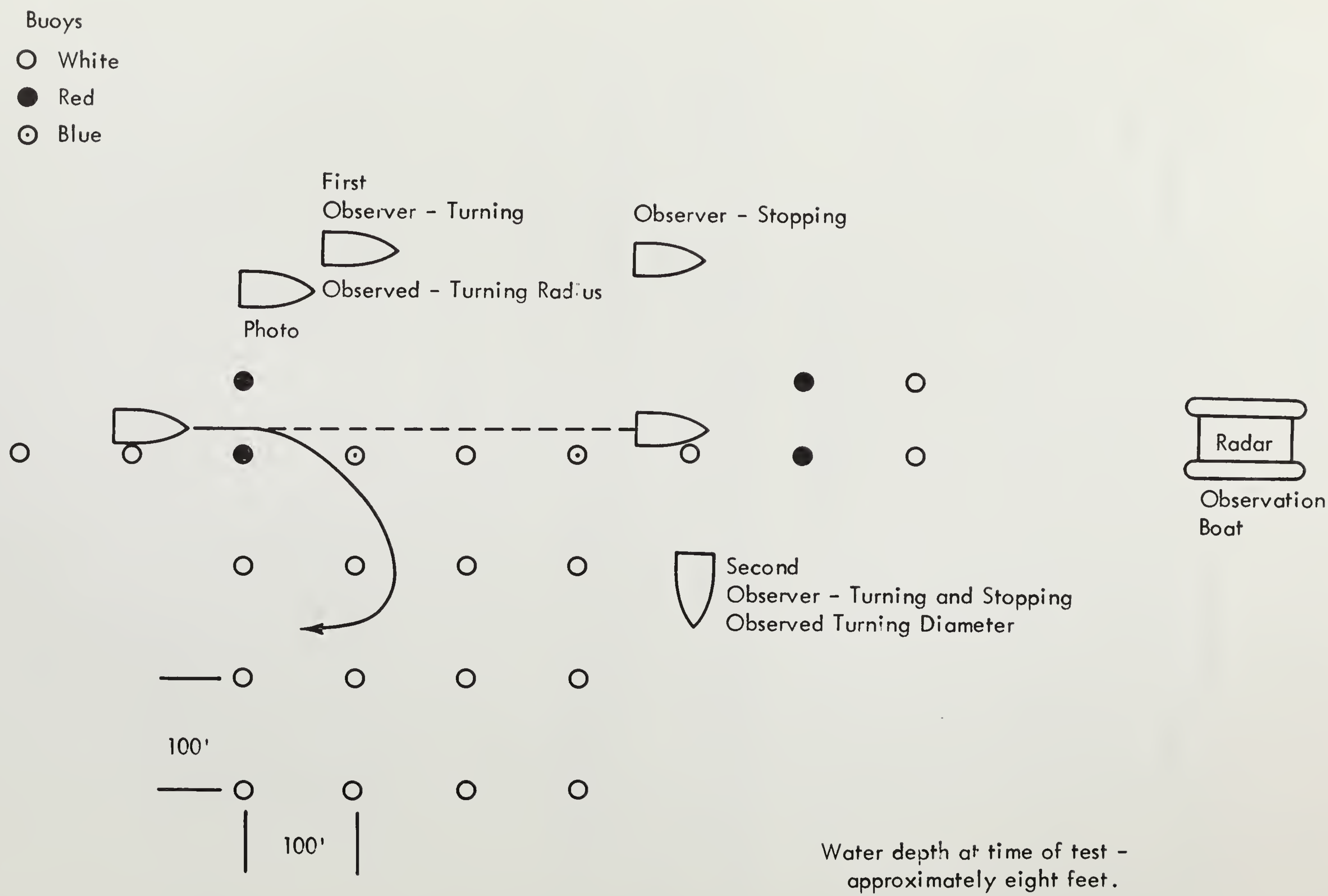


Figure 1. Avoidance Capability Course

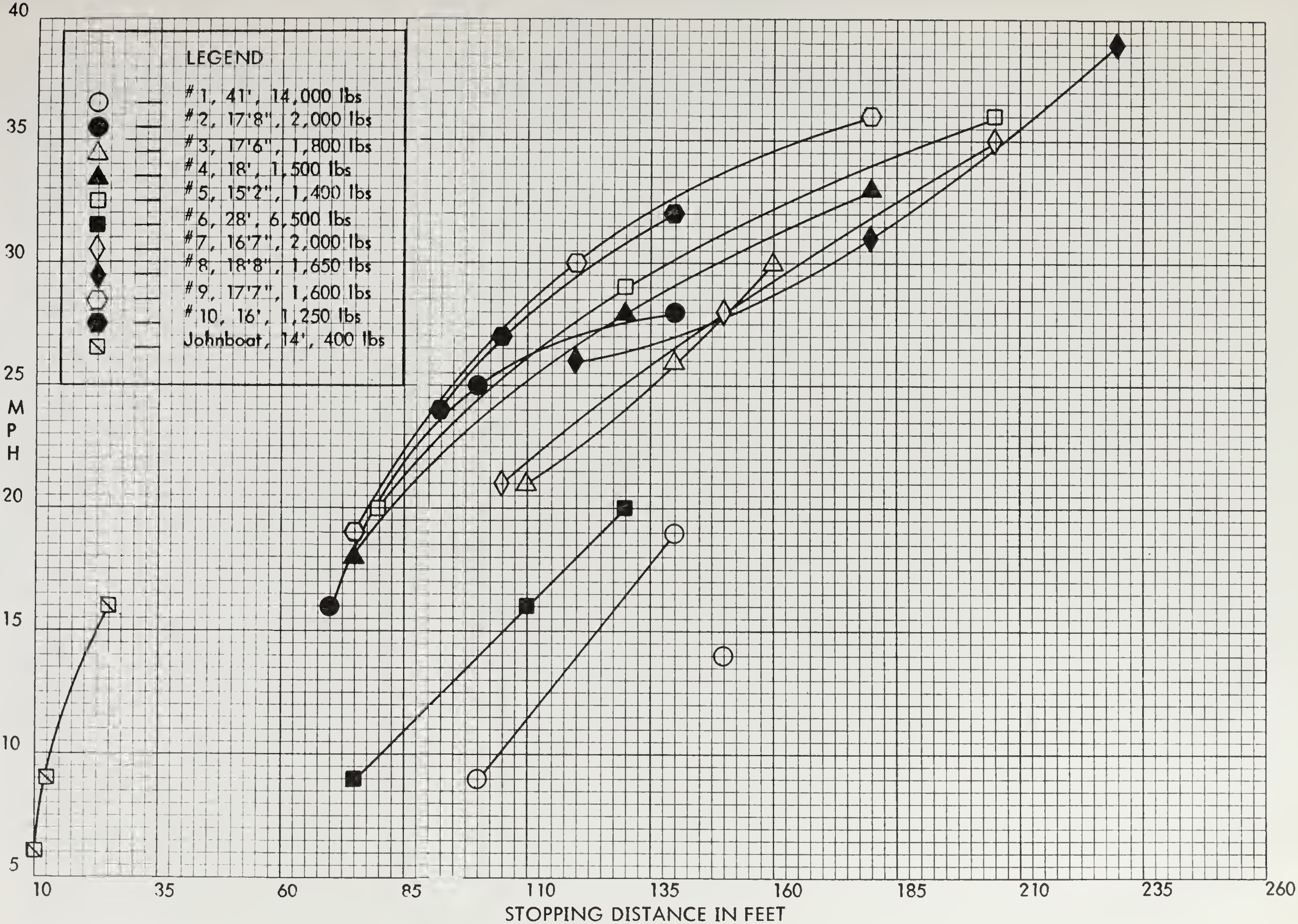


Figure 2. Speed vs. Stopping Distance, All Boats - 3 Speeds

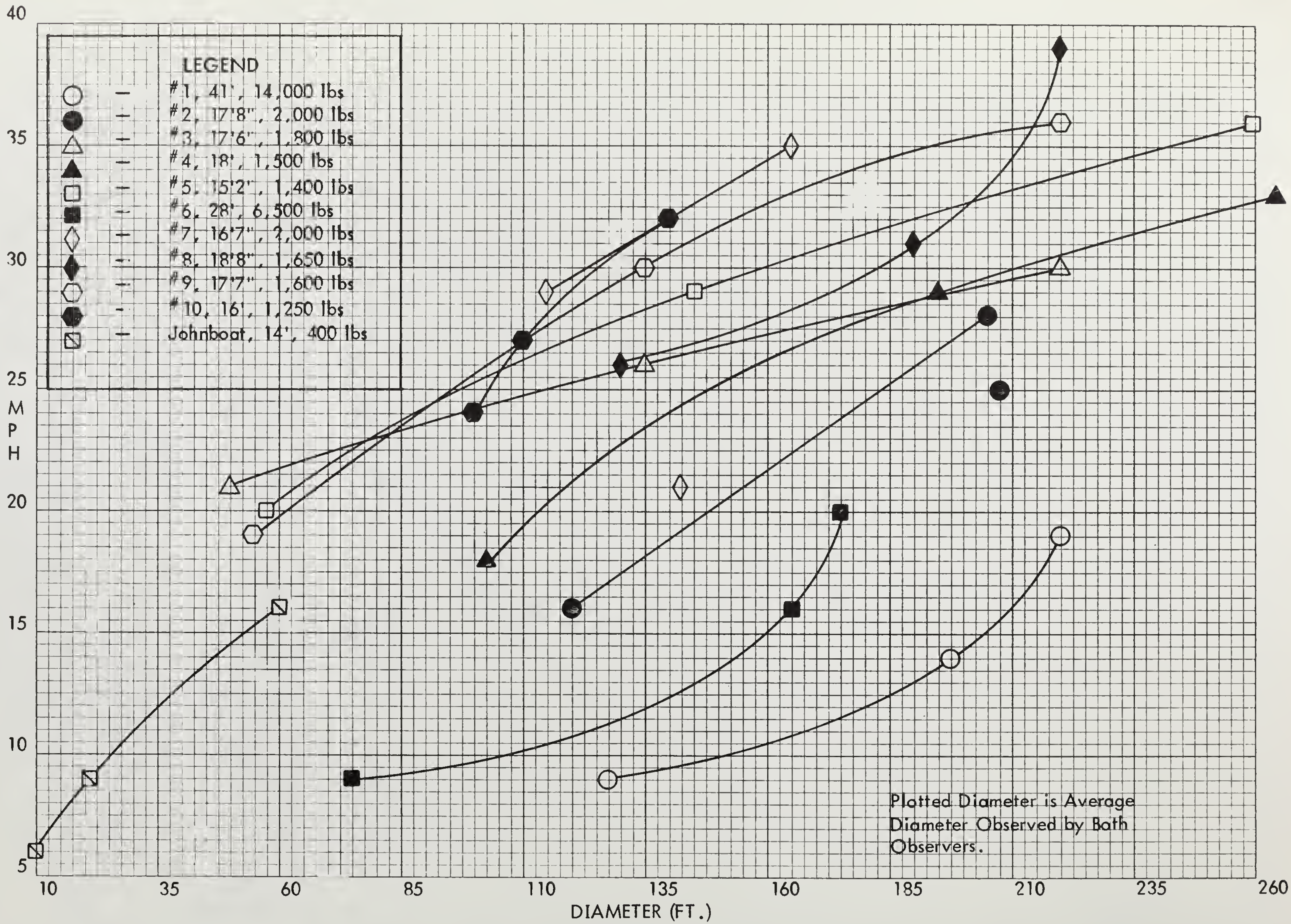


Figure 3. Speed vs. Turning Diameter, All Boats - 3 Speeds

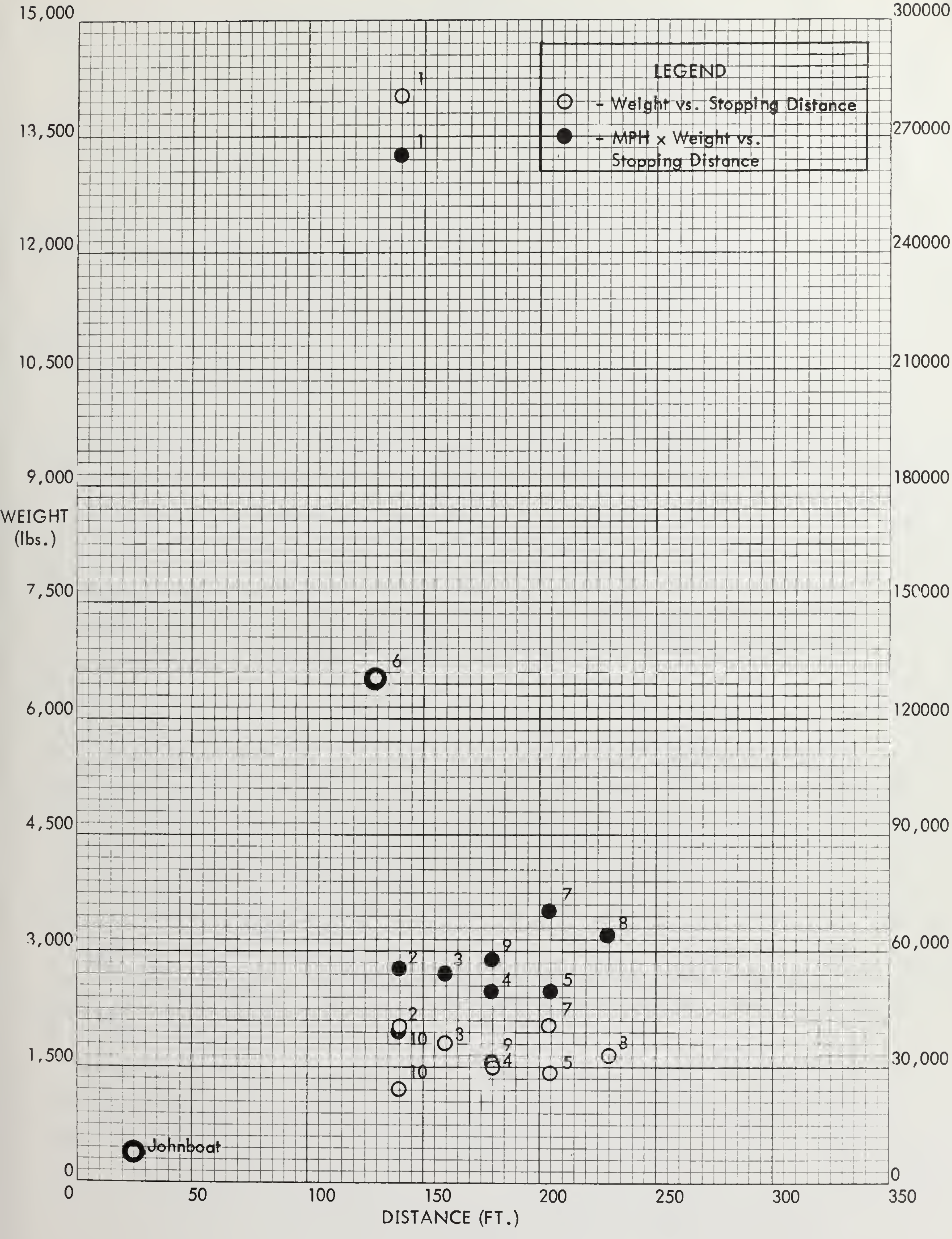


Figure 4. Weight vs. Stopping Distance at Full Throttle

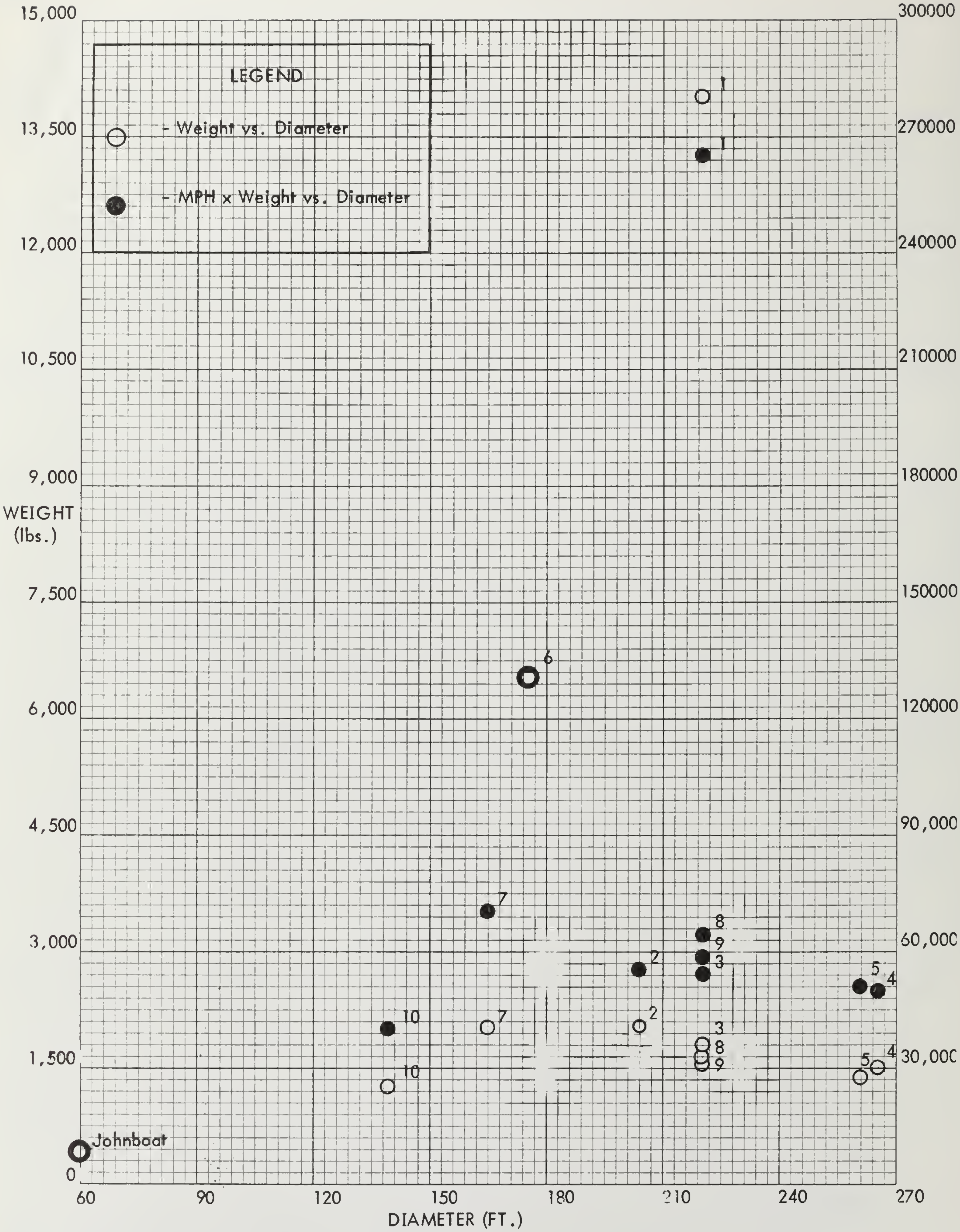


Figure 5. Weight vs. Turning Diameter at Full Throttle

TABLE I

STOPPING/MANEUVERING TESTS DATA SUMMARY

	Full	Cruise or 3/4	1/2 Throttle
Boat No. 1 - 41 feet			
Weight: 14,000 lbs			
Speed	19 mph	14 mph	9 mph
Stopping Distance	140'	150'	100'
Turn to Stbd. (diameter)	240' dn to 200'	220' dn to 175'	130' dn to 125'
Turn to Stbd (Cut Throttle)	--	190' dn to 100'	--
Boat No. 6 - 28 feet			
Weight: 6,500 lbs			
Speed:	20 mph	16 mph	9 mph
Stopping Distance	130' long glide	110' long glide	70-80' long glide
Turn to Stbd. (diameter)	200' dn to 150'	190' dn to 140'	80' dn to 70'
Turn to Stbd. (Cut Throttle)	160' dn to 40'	180' dn to 45'	80' dn to 45'
Boat No. 7 - 16'7"			
Weight: 2,000 lbs			
Speed	35 mph	28 mph	21 mph
Stopping Distance	205'	150'	105'
Turn to Stbd. (diameter)	210' dn to 120'	170' dn to 60'	110' to 175'
Turn to Stbd. (Cut Throttle)	180' dn to 70'	160' dn to 50'	110' to 130'
Boat No. 2 - 17'8"			
Weight: 2,000 lbs			
Speed	28 mph	25 mph	16 mph
Stopping Distance	140'	100'	70'
Turn to Stbd. (diameter)	220' dn to 190'	230' dn to 185'	120' all the way
Turn to Stbd. (Cut Throttle)	160' to ---	130' dn to 75'	100' dn to 75'
Boat No. 3 - 17'6"			
Weight: 1,800 lbs			
Speed	30 mph	26 mph	21 mph
Stopping Distance	160'	140'	110'
Turn to Stbd. (diameter)	260' dn to 180'	160' dn to 110'	60' dn to 40'
Turn to Stbd. (Cut Throttle)	220' to ---	160' dn to 90'	80' dn to 40'

TABLE I (cont.)

STOPPING/MANEUVERING TESTS DATA SUMMARY

	Full	Cruise or 3/4	1/2 Throttle
Boat No. 8 - 18'8"			
Weight: 1650 lbs.			
Speed	39 mph	31 mph	26 mph
Stopping Distance	230'	180'	120'
Turn to Stbd. (diameter)	220' Diameter	190' Diameter	130' Diameter
Turn to Stbd.(Cut Throttle)	220' Diameter	170' Diameter	120' Diameter
Boat No.9 - 17'7"			
Weight: 1600 lbs.			
Speed	36 mph	30 mph	19 mph
Stopping Distance	180'	120'	75'
Turn to Stbd. (diameter)	220' all the way	160' dn to 110'	70' dn to 40'
Turn to Stbd. (Cut Throttle)	180' dn to 50'	150' dn to 55'	60' dn to 30'
Boat No.4 - 18 feet			
Weight: 1500 lbs.			
Speed	33 mph	28 mph	18 mph
Stopping Distance	180'	130'	75'
Turn to Stbd. (diameter)	300' dn to 230'	210' dn to 180'	120' dn to 85'
Turn to Stbd. (Cut Throttle)	210' dn to 80'	170' dn to 65'	100' dn to 40'
Boat No. 5 - 15'2"			
Weight: 1400 lbs.			
Speed:	36 mph	29 mph	20 mph
Stopping Distance	205'	130'	80'
Turn to Stbd. (diameter)	270' dn to 250'	160' dn to 130'	60' dn to 55'
Turn to Stbd.(Cut Throttle)	180' to ---	130' dn to 30'	60' dn to 30'
Boat No.10 - 16 feet			
Weight: 1250 lbs.			
Speed:	32 mph	27 mph	24 mph
Stopping Distance	140'	105'	90-95'
Turn to Stbd. (diameter)	140'	110'	100'
Turn to Stbd. (Cut Throttle)			

TABLE I (concluded)
STOPPING/MANEUVERING TESTS DATA SUMMARY

	Full	Cruise or 3/4	1/2 Throttle
Boat No. (CG Johnboat) 14' Weight: 400 lbs			
Speed:	16 mph	9 mph	6 mph
Stopping Distance	25'	12'	10'
Turn to Stbd. (diameter)	60' all the way	28' dn to 15'	12' dn to 8'
Turn to Stbd. (Cut Throttle)	40' dn to 15'	24' dn to 8'	12' dn to 2'